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WATER RESOURCES STUDY, TRINITY RIVER BASIN, TEXAS. STUDY OF POTENTIAL NEEDS AND VALUE OF WATER FOR MUNICIPAL, INDUSTRIAL, AND QUALITY CONTROL PURPOSES

Public Health Service
Dallas, Texas

October 1962

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WATER RESOURCES STUDY

TRINITY RIVER BASIN, TEXAS

Study of Potential Needs and Value of Water for Municipal, Industrial, and Quality Control Purposes

(This is a working draft containing
detailed information and backup data
not included in the final report.)

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region VII
Dallas, Texas

In Cooperation with the

DEPARTMENT OF THE ARMY
U. S. Army Engineer Districts
Fort Worth and Galveston, Texas

OCTOBER 1962

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I. INTRODUCTION

Authority

In a letter dated June 8, 1959, the Corps of Engineers, Fort Worth District, requested "HEW views and recommendations on present and prospective municipal and industrial water supply needs in Trinity River Basin, including Houston municipal and industrial complex." The request was subsequently expanded to cover a 100-year future period and to include the needs for storage of water for quality control purposes.

This study has been made in accordance with: (1) the Water Supply Act of 1958 (Public Law 85-500, Title III) and a Memorandum of Agreement between the Department of the Army and the Department of Health, Education, and Welfare, dated November 4, 1958; and (2) the Federal Water Pollution Control Act (Public Law 84-660) as amended by Public Law 87-88.

Purpose and Scope

The primary objective of this report is the determination of water requirements for municipal, industrial, and water quality control purposes to the year 2070 in the Trinity River basin including the Houston municipal and industrial complex. Estimates are made of the benefits attributable to the storage of water for meeting these requirements in proposed Federal reservoirs.

To arrive at these needs, studies are made of the economic and demographic variables which affect water consumption. These are then projected to the terminal year of the study (2070), combined with projected unit water usage and translated into municipal and industrial water requirements. The amounts of wastes which result from these uses are calculated and the quantity of water required to preserve stream quality is determined.

In addition to determining requirements, a basinwide plan for supplying these needs is developed, which provides for orderly and efficient utilization of potential water resources within the basin with full recognition of all permits, commitments, and agreements executed by local interests.

Acknowledgments

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3. Texas Employment Commission, Austin and Dallas, Texas
4. Texas Water Commission, Austin, Texas
5. Texas State Department of Health, Austin, Texas
6. U. S. Army Engineer District--Fort Worth, Fort Worth, Texas
7. U. S. Army Engineer District--Galveston, Galveston, Texas
8. U. S. Geological Survey, Ground Water Branch, Houston, Texas
9. U. S. Study Commission-Texas, Houston, Texas
10. Water Departments, officials, and Chambers of Commerce of the following cities:

    Athens, Texas
    Crockett, Texas
    Dallas, Texas
    Fort Worth, Texas
    Galveston, Texas
    Houston, Texas
    Palestine, Texas

II. SUMMARY AND CONCLUSIONS

Summary

1. The study area comprises 46 counties in and surrounding the Trinity River basin. It is situated in eastern Texas and extends from the Oklahoma-Texas boundary to the Gulf of Mexico. The Trinity River basin is roughly 70 miles wide, 350 miles long, and contains an area of about 17,760 square miles.

2. These 46 counties contain some of the most densely populated lands of the State of Texas. Although the study area contains only 15 percent of the land area, it harbored 43 percent of the State's population in 1960. Except for the standard metropolitan statistical areas (SMSA's) of Houston, Dallas, Fort Worth, Beaumont, Port Arthur, and Galveston-Texas City, the area is rural in character. In general, the SMSA's have been experiencing rapid population growth while the remainder of the area has been declining.

3. The study area is in a period of rapid economic expansion. The metropolitan areas have become leading manufacturing centers in the Nation. Dallas and Fort Worth rank high in aircraft and electronic manufacture, and the growth of the petrochemical industry in Houston and the other gulf coast metropolitan areas can only be described as colossal.

4. There are 42 existing, under construction, and authorized reservoirs in the study area with capacities greater than 5,000 acre-feet representing a combined volume of stored surface water in excess of 16 million acre-feet. Twenty-five of these reservoirs are within the Trinity River basin. Reported ground water pumpage in 1958 amounted to more than 346,000 acre-feet.

5. There are 25 proposed reservoirs and reservoir enlargements in the study area, 19 of which are in the Trinity River basin. There is Federal interest in only four of the planned Trinity River projects. These are Tennessee Colony, Lakeview, and Wallisville Reservoirs and the enlargement of Lavon Reservoir.

6. Average daily municipal and industrial water demands in the study area approximated 952 million gallons in 1958. Other major water uses are irrigation, navigation, and recreation.

7. In January 1958, there were 198 municipal and industrial waste treatment plants discharging into the Trinity River basin, most of which were operating efficiently within their design capacities.

8. The mineral quality of the waters in the Trinity basin may be described as good to very good. High solids concentrations are generally confined to the coastal region and are due to the influx of brackish waters from the Gulf of Mexico.

9. Despite good waste treatment practice, the organic quality of a large part of the Trinity basin is very poor. Insufficient tributary dilution and reaeration cause anaerobic conditions to exist generally in the reach between Fort Worth and Rosser in Kaufman County. Downstream from this point rapid recovery occurs, almost overcoming the effects of organic pollution upon reaching the San Jacinto County line.

10. All of the projections and estimates contained in this report presuppose: (1) the existence of the Trinity River navigation canal to Fort Worth; and (2) a design drouth similar to the one which occurred in the years 1950-1957.

Conclusions

1. Efficient development of all of the water resources of the Trinity River basin is essential to the continued growth of the area. And to attain full utilization of these resources for municipal, industrial, agricultural, navigation, and recreation purposes will require abatement of the present pollution in the upper basin as well as control of future pollution throughout the area. Therefore, provision of water to maintain at least minimum quality conditions in the river must be made a part of the water supply plan until such time as future advances in waste treatment technology can economically provide for removal of residual pollutants before they reach the stream.

2. The study area's population is expected to reach 12 million by the year 2020 and 23 million by the year 2070. This represents an increase over 1960 of 203 percent and 465 percent, respectively.

3. Projected municipal and industrial water demands are 5,099 mgd (million gallons per day) in 2020 and 9,650 mgd in 2070 for the 46-county study area. For the Trinity River basin alone, the projected municipal and industrial demands are 2,080 mgd in 2020 and 3,918 in 2070.

4. With the water supply plan as herein presented, the potential water resource in the Trinity River basin is sufficient to satisfy all projected water requirements within the basin, including the diversion of the presently agreed amount to the city of Houston until the year 2070.

5. To maintain water quality within the Trinity River basin and on the Buffalo Bayou watershed will require releases from storage of about 1,650 mgd in 2020 and 3,600 mgd in 2070 based on 90 percent removal of BOD and 15 percent removal of total dissolved solids.

6. Maintenance of water quality within the Trinity River basin beyond the year 2020 is dependent upon the improvement of waste treatment techniques.

7. With increased water reuse and minimal use of water for cooling, the projected municipal and industrial study area water needs until 2070 can be satisfied.

8. The study area outside the Trinity River basin, with the exception of Houston which will receive 840 mgd, will be served by sources outside the Trinity River basin.

9. The estimated benefits of storage by purpose for the six proposed Federal projects in the Trinity River basin are shown in Tables IX-1 and IX-2, pages IX-1 and IX-2. The benefits shown in Table IX-3, page IX-3, for water quality control represent the value of storage for this purpose at the reservoir site plus the cost of transporting the required amount of water in the case of Tennessee Colony Reservoir.

III. DESCRIPTION OF THE STUDY AREA

General

The study area comprises 46 counties in and surrounding the Trinity River basin as shown in Figure III-1. It represents approximately 15 percent of the land area of the State of Texas and in 1960 harbored 43 percent of the State's population.

The Trinity River basin is an area about 70 miles wide extending from north-central Texas southeasterly about 350 miles to Galveston Bay. Measured along its streambed, the river has a total length of approximately 650 miles and drains an area of about 17,760 square miles. The watershed is located entirely within the State of Texas. It is bounded on the north by the Red River, on the east by the Sabine and Neches Rivers, on the west by the Brazos and San Jacinto Rivers, and on the south by Galveston Bay.

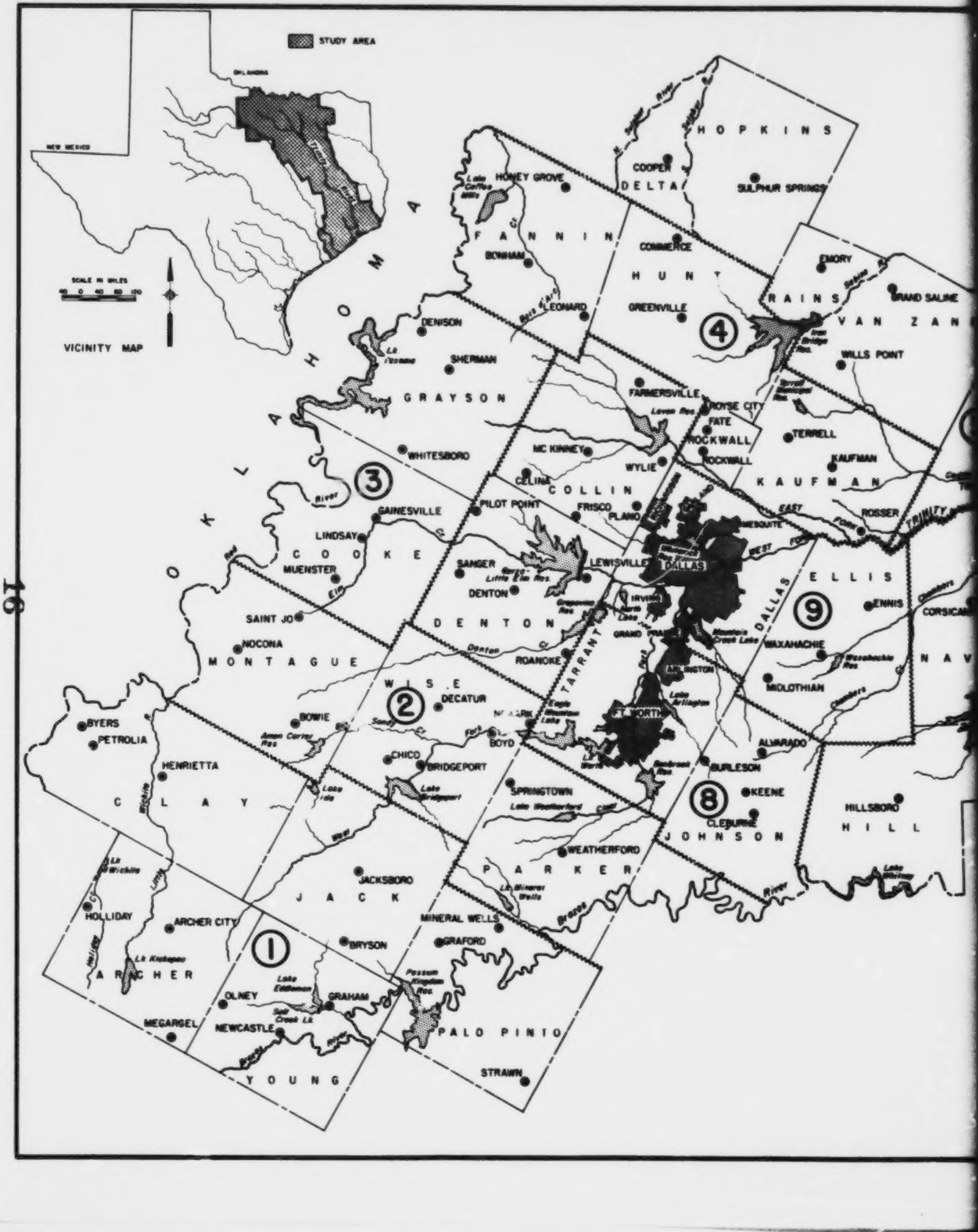
Geography

The upper tributaries of the Trinity River drain a hilly fan-shaped area and converge in the vicinity of Dallas to form the main stem. Below this point, the terrain changes generally to gently sloping hills. The river rises at an elevation of about 1,250 feet, drops rapidly to about 400 feet at Dallas, and discharges to Galveston Bay at sea level. The southeastern two-thirds of the basin is devoted to general farming while the northwestern portion is used principally for ranching. The general appearance of the basin is one of smooth plains with distinct escarpments facing the northwest and growing in predominance toward the headwaters.

The climate of the study area is extremely diverse. It varies from dry, subhumid in the northwest to humid along the coast of the Gulf of Mexico. Heavy rainstorms are common throughout the area and occasional tropical storms enter the area from the gulf. Average winter and summer temperatures in the northwestern half of the area vary from 42°F to 85°F, and in the southeastern half from 54°F to 83°F. Mean annual rainfall varies from 27 inches at the extreme northwestern edge of the area to 51 inches along the gulf coast.

The growing season is about 232 days in the northeastern portion of the area and, in the southeastern portion, averages about 277 days.

Runoff within the area is characterized by large variations annually as well as seasonally. Within the Trinity River basin, periods of zero flow have been experienced on all tributaries of the river with the exception of the West Fork between Fort Worth and Dallas where upstream sewage releases account for the base flow of the stream during dry periods. The estimated average annual natural runoff of the entire Trinity River basin for the period 1941-1956 was 5,770,200 acre-feet. 16/


STUDY AREA
OKLAHOMA
NEW MEXICO
SCALE IN MILES
VICINITY MAP
OKLAHOMA
HOPKINS
COOPER
DELTA
SULPHUR SPRINGS
HONEY GROVE
Lake Coffee Mills
FANNIN
BONHAM
COMMERCE
HUNT
GREENVILLE
EMORY
RAINS
GRAND SALINE
VAN ZANDT
WILLS POINT
Iron Bridge Res.
LEONARD
DENISON
Lk. Texoma
SHERMAN
GRAYSON
FARMERSVILLE
Lavon Res.
ROYSE CITY
FATE
ROCKWALL
TERRELL
KAUFMAN
WHITESBORO
MC KINNEY
WYLIE
CELINA
COLLIN
PILOT POINT
FRISCO
PLANO
MESQUITE
ROSSER
TRINITY
GAINESVILLE
LINDSAY
COOKE
MUENSTER
SANGER
LEWISVILLE
Little Elm Res.
DALLAS
DENTON
IRVING
ELLIS
ENNIS
CORSICANA
SAINT JO
NOCONA
MONTAGUE
DENTON
ROANOKE
TARRANT
GRAND PRAIRIE
Mountain Creek Lake
WAXAHACHIE
MIDLOTHIAN
DALLAS
NAVARRO
WISE
DECATUR
BOWIE
Amon Carter Res.
ARLINGTON
Lake Arlington
BYERS
PETROLIA
HENRIETTA
CHICO
BRIDGEPORT
Lake Bridgeport
BOYD
Eagle Mountain Lake
FT. WORTH
Lk. Worth
Benbrook Res.
ALVARADO
BURLESON
CLAY
SPRINGTOWN
Lake Weatherford
KEENE
CLEBURNE
JOHNSON
HILLSBORO
HILL
WEATHERFORD
PARKER
Lk. Mineral Wells
JACKSBORO
JACK
MINERAL WELLS
GRAFORD
HOLLIDAY
ARCHER CITY
BRYSON
Lk. Kickapoo
ARCHER
Possum Kingdom Res.
Lake Eddleman
OLNEY
GRAHAM
Salt Creek Lk.
MEGARGEL
NEWCASTLE
PALO PINTO
YOUNG
STRAWN
Brazos
Red River
Elm Fk.
West Fork
East Fork
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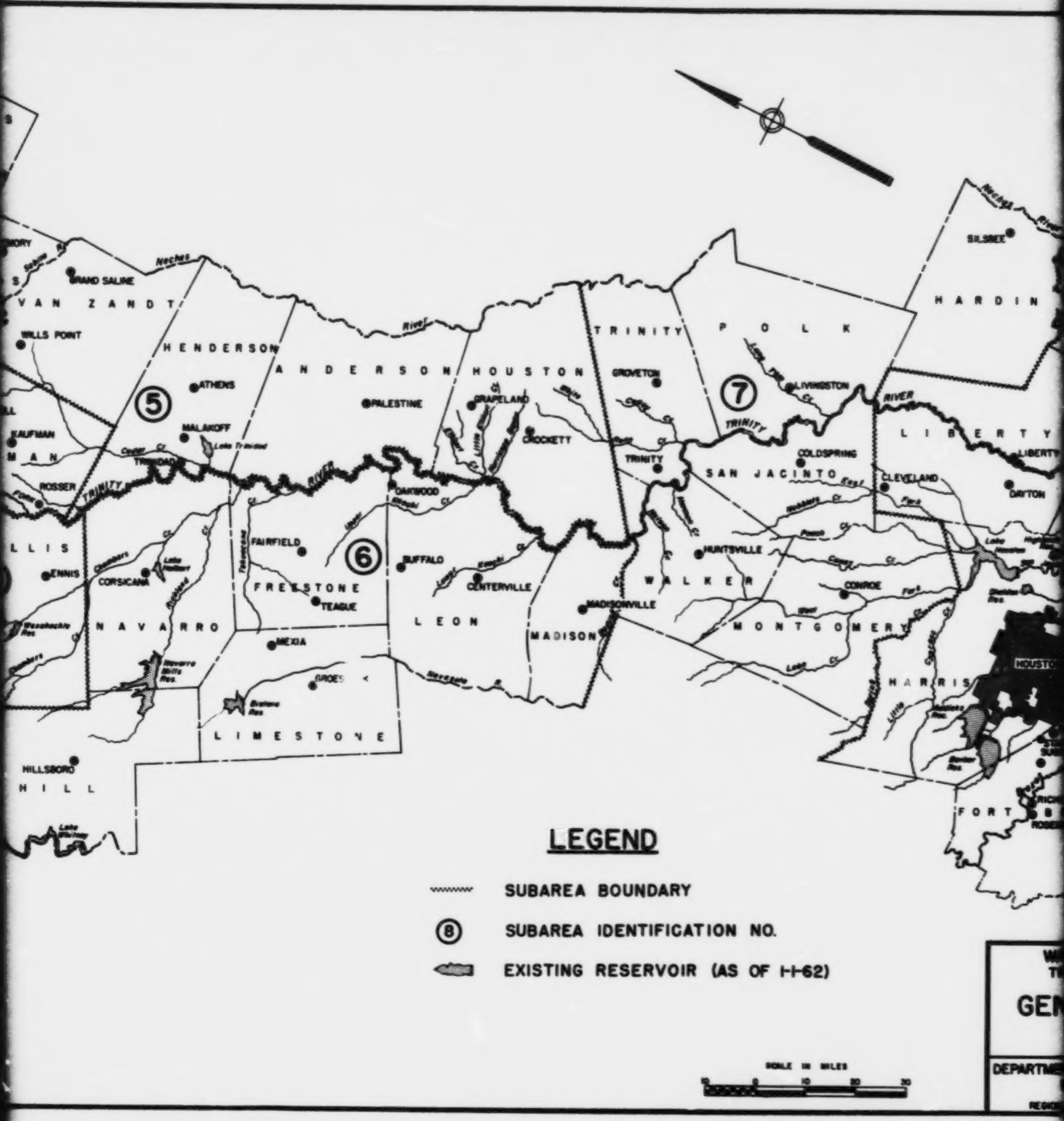

VAN ZANDT
GRAND SALINE
WILLS POINT
HENDERSON
ATHENS
MALAKOFF
Lake Trinidad
TRINIDAD
KAUFMAN
ROSSER
ANDERSON
PALESTINE
HOUSTON
GRAPELAND
CROCKETT
TRINITY
GROVETON
POLK
LIVINGSTON
HARDIN
SILSBEE
LIBERTY
DAYTON
SAN JACINTO
COLDSPRING
CLEVELAND
WALKER
HUNTSVILLE
MONTGOMERY
CONROE
HARRIS
HOUSTON
FORT
ELLIS
ENNIS
NAVARRO
CORSICANA
Navarro Mills Res.
FREESTONE
FAIRFIELD
TEAGUE
OAKWOOD
BUFFALO
LEON
CENTERVILLE
MADISON
MADISONVILLE
LIMESTONE
MEXIA
GROESBECK
HILLSBORO
HILL
Neches River
Trinity River
Navasota R.
Lake Houston
Barker Res.
Addicks Res.
5
6
7
LEGEND
SUBAREA BOUNDARY
8
SUBAREA IDENTIFICATION NO.
EXISTING RESERVOIR (AS OF 1-1-62)
SCALE IN MILES
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10
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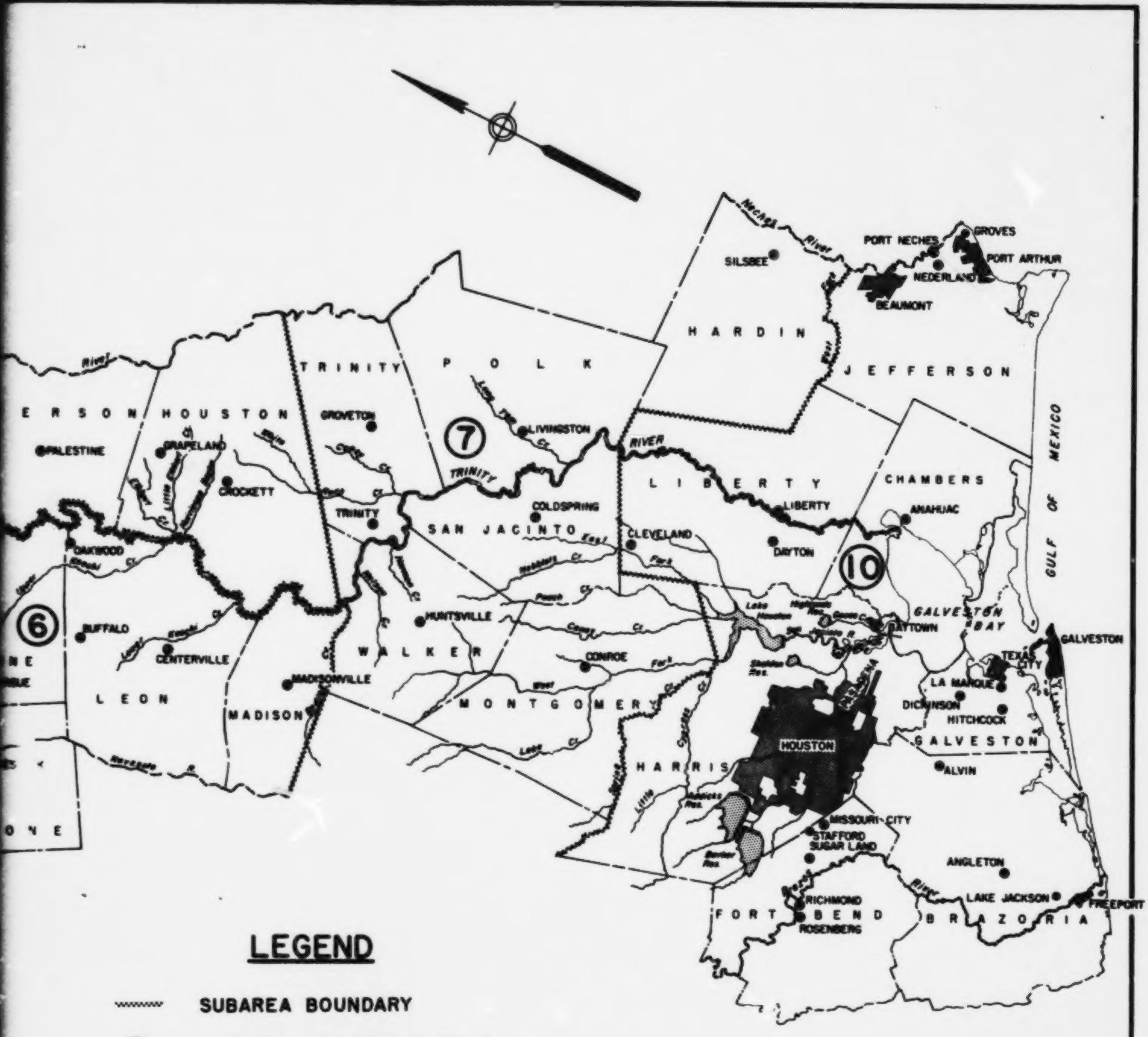
DEPARTME



POLK
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MADISON
MONTGOMERY
HARRIS
GALVESTON
FORT BEND
BRAZORIA
GULF OF MEXICO
GALVESTON BAY
⑥
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⑩
SILSBEE
PORT NECHES
GROVES
PORT ARTHUR
NEDERLAND
BEAUMONT
GROVETON
LIVINGSTON
PALESTINE
GRAPELAND
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LIBERTY
DAYTON
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OAKWOOD
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HUNTSVILLE
CONROE
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TEXAS CITY
GALVESTON
LA MARQUE
DICKINSON
HITCHCOCK
ALVIN
MISSOURI CITY
STAFFORD
SUGAR LAND
ANGLETON
LAKE JACKSON
FREEPORT
RICHMOND
ROSENBERG
Neches River
River
Trinity River
Lake Houston
Brazos River
Navasota R.
Barker Res.
Addicks Res.
Sheldon Res.

LEGEND

〰 SUBAREA BOUNDARY

⑧ SUBAREA IDENTIFICATION NO.

▨ EXISTING RESERVOIR (AS OF 1-1-62)

SCALE IN MILES

10 0 10 20 30

WATER RESOURCES STUDY
TRINITY RIVER BASIN—TEXAS

GENERAL LOCATION MAP

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE III-1

Characteristics of the Subareas

The study area was divided into 10 subareas for the purpose of providing suitable size base areas for study, at the same time maintaining a reasonable degree of homogeneity of economic, water resource, and geographic factors. The locations and boundaries of the subareas are shown in Figure III-1.

The principal characteristics of each of the subareas are shown in Table III-1, 17/ Appendix E.

IV. WATER RESOURCES IN THE STUDY AREA

General

There has been considerable surface and ground water resource development within the study area in the past. At present there are more than 40 major reservoirs having a capacity of 5,000 acre-feet or more, and 79 reservoirs with capacities under 5,000 acre-feet. In 1958, the Texas Board of Water Engineers received reports on 1,385 wells within the study area which produced more than 112,000 million gallons of water. [3]

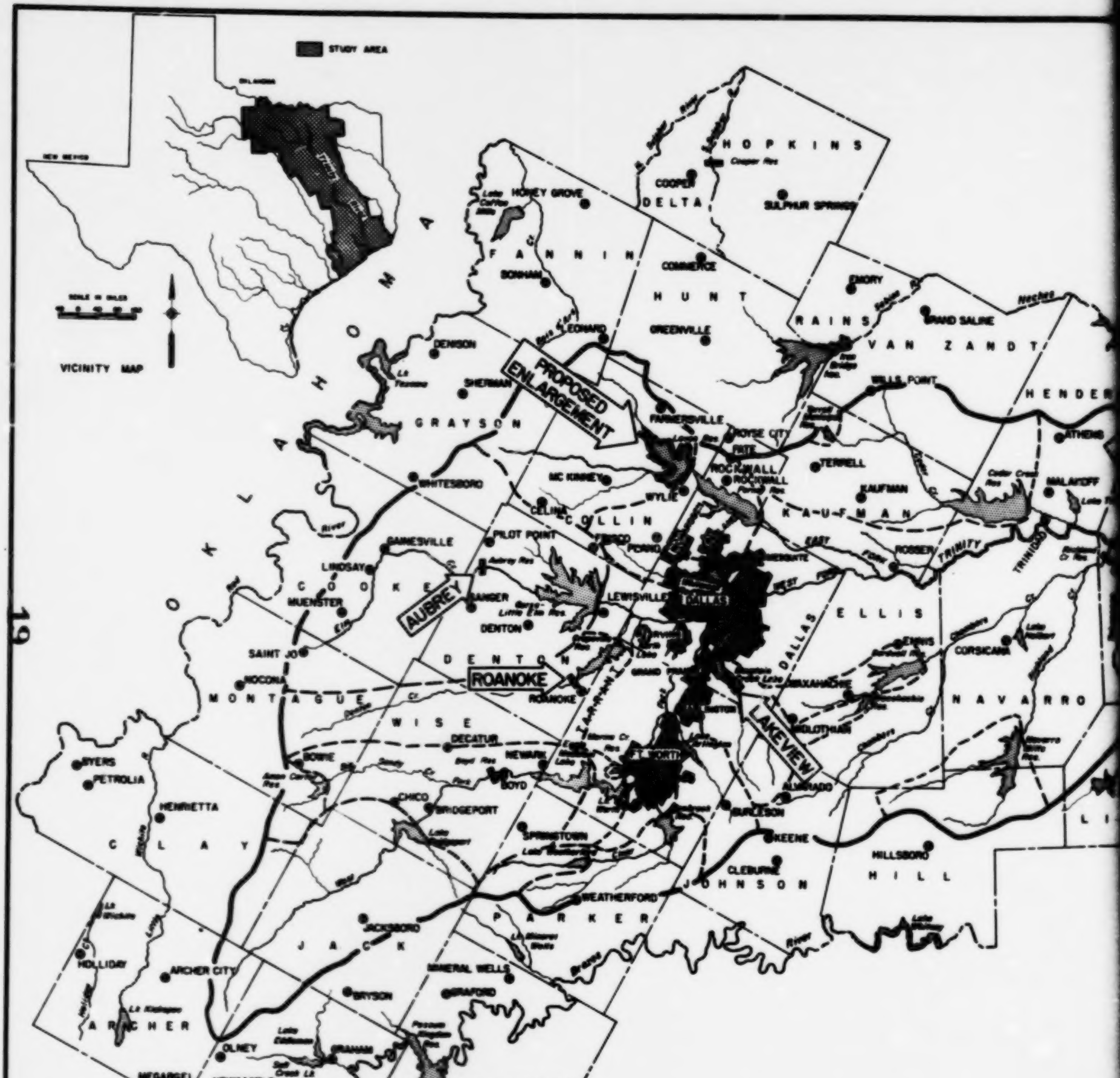
Existing Reservoirs

The locations of the 42 major reservoirs in the study area are shown in Figure IV-1. Investigation of the 17 reservoirs outside the Trinity River basin was restricted to determination of terminal year yields and the demands on these yields as they affect interbasin transfer of water. A list of all major study area reservoirs arranged by subarea showing the river basin, total capacity in acre-feet, date of construction, ownership, and type of use is given in Table IV-1, [11,12] Appendix E.

The two primary measures of water quality used in this study are mineral and organic solids. Indicators of these qualities are total dissolved solids concentration and biochemical oxygen demand (BOD), respectively.

The total dissolved solids concentrations within the basin vary from a low of 100 mg/l to a high of 1,000 mg/l. Concentrations in excess of 500 mg/l are very few and are confined to the lower coastal region. These high concentrations are due to brackish Gulf of Mexico waters which affect the mineral quality of the river as far as 40 miles inland. In general, the mineral quality of the Trinity basin can be described as good to very good.

On the other hand, the organic quality of a large part of the basin is very poor. Above Fort Worth, and below the San Jacinto County line, the organic quality of the basin can be classified as good. This is due to light pollution loads entering the basin above Fort Worth and the self-recovery of the stream from the high loads imposed by the Fort Worth and Dallas complex by the time it reaches the San Jacinto County line. Below the confluence of Marine Creek with the West Fork in Fort Worth and downstream to Rosser in Kaufman County, the conditions in the river are generally anaerobic and associated offensive odors persist. Downstream from Rosser, sufficient tributary dilution and reaeration occur, almost overcoming the effects of the organic pollution upon reaching the San Jacinto County line. [13]


STUDY AREA
NEW MEXICO
OKLAHOMA
SCALE IN MILES
VICINITY MAP
O K L A H O M A
HOPKINS
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SULPHUR SPRINGS
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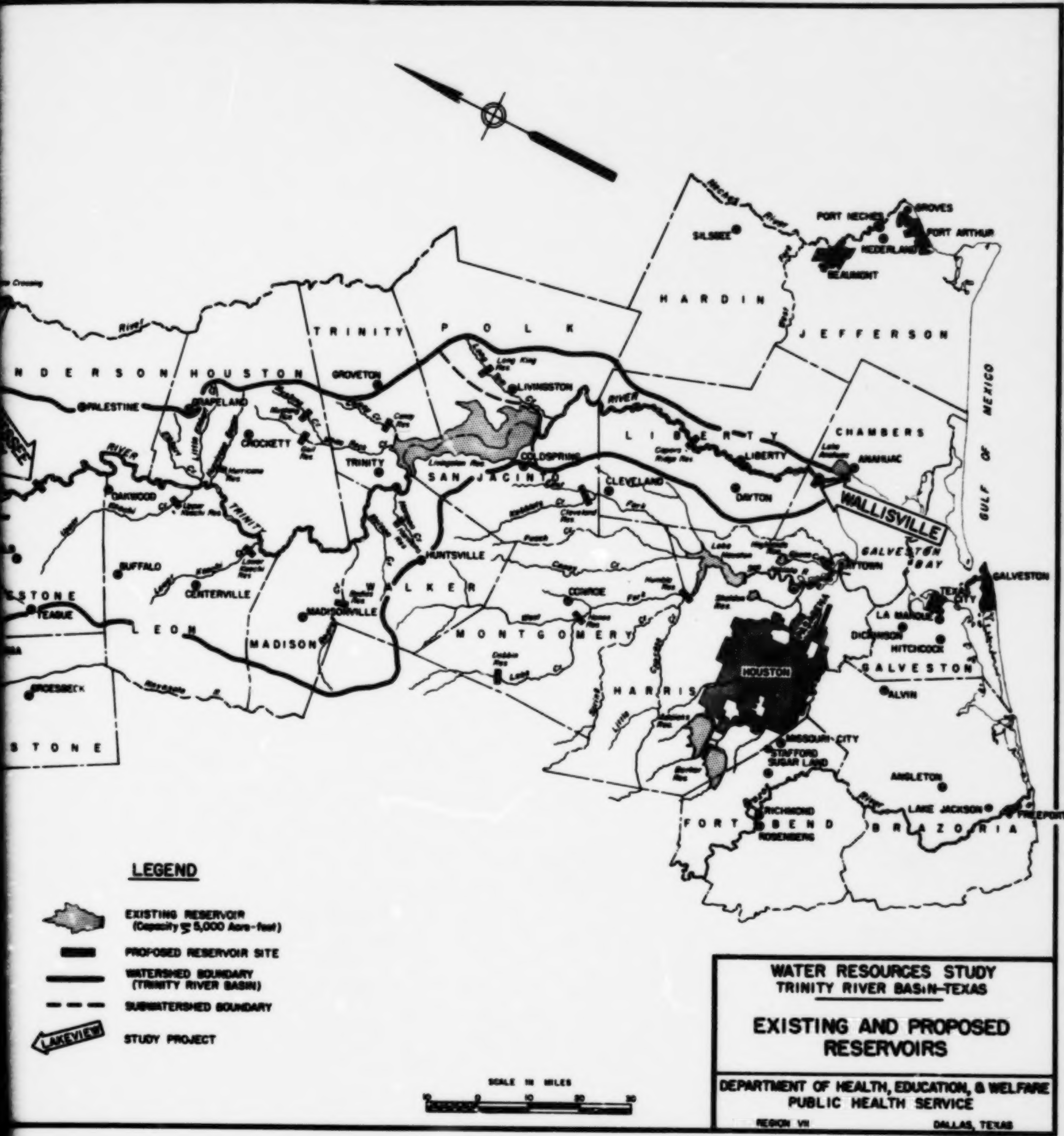
Lake Coffee Mill
FANNIN
BONHAM
COMMERCE
HUNT
GREENVILLE
EMORY
RAINS
GRAND SALINE
VAN ZANDT
Neches
LEONARD
DENISON
SHERMAN
GRAYSON
PROPOSED ENLARGEMENT
FARMERSVILLE
ROYSE CITY
FATE
ROCKWALL
WILLS POINT
HENDER
ATHENS
TERRELL
KAUFMAN
Cedar Creek Res
MALAKOFF
WHITESBORO
MC KINNEY
WYLIE
CELINA
COLLIN
PILOT POINT
FRISCO
GAINESVILLE
LINDSAY
COOKE
Aubrey Res
AUBREY
SANGER
LEWISVILLE
DALLAS
MESQUITE
ROSSER
TRINITY
TRINIDAD
MUENSTER
DENTON
Little Elm Res
ELLIS
SAINT JO
DENTON
ROANOKE
NOCONA
MONTAGUE
WISE
ROANOKE
GRAND PRAIRIE
LAKEVIEW
WAXAHACHIE
ENNIS
CORSICANA
NAVARRO
MIDLOTHIAN
BYERS
PETROLIA
DECATUR
BOWIE
NEWARK
FT. WORTH
HENRIETTA
BOYD
CHICO
BRIDGEPORT
ALVARADO
BURLESON
CLAY
SPRINGTOWN
Lake Bridgeport
Lake Weatherford
KEENE
CLEBURNE
JOHNSON
HILLSBORO
HILL
WEATHERFORD
PARKER
JACKSBORO
JACK
Brazos
River
HOLLIDAY
ARCHER CITY
MINERAL WELLS
BRYSON
GRAFORD
Lk Kickapoo
ARCHER
OLNEY
GRAHAM
Possum Kingdom Res
NEWCASTLE
MEGARGEL
PALO PINTO
YOUNG
STRAWN


TRINITY
POLK
HARDIN
JEFFERSON
HOUSTON
LIBERTY
CHAMBERS
SAN JACINTO
WALKER
LEON
MADISON
MONTGOMERY
HARRIS
GALVESTON
FORT BEND
BRAZORIA
GULF OF MEXICO
GALVESTON BAY
WALLISVILLE
LAKEVIEW
PALESTINE
GRAPELAND
CROCKETT
GROVETON
LIVINGSTON
COLDSPRING
TRINITY
OAKWOOD
BUFFALO
CENTERVILLE
TEAGUE
GROESBECK
HUNTSVILLE
MADISONVILLE
CONROE
CLEVELAND
LIBERTY
DAYTON
ANAHUAC
BAYTOWN
HOUSTON
SILSBEE
PORT NECHES
GROVES
NEDERLAND
PORT ARTHUR
BEAUMONT
TEXAS CITY
GALVESTON
LA MARQUE
DICKINSON
HITCHCOCK
ALVIN
MISSOURI CITY
STAFFORD
SUGAR LAND
RICHMOND
ROSENBERG
ANGLETON
LAKE JACKSON
FREEPORT
Livingston Res
Long King Res
Lake Houston
Lake Anahuac
Cleveland Res
Cobbs Res
Addicks Res
Barker Res
Upper Keechi Res
Lower Keechi Res
Hurricane Res
SCALE IN MILES
10
0
10
20
30

LEGEND

	EXISTING RESERVOIR (Capacity ≥ 5,000 Acre-feet)
	PROPOSED RESERVOIR SITE
	WATERSHED BOUNDARY (TRINITY RIVER BASIN)
	SUBWATERSHED BOUNDARY
LAKEVIEW	STUDY PROJECT

WATER RESOURCES STUDY
TRINITY RIVER BASIN–TEXAS

EXISTING AND PROPOSED RESERVOIRS

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV–1

Pertinent data for the 20 existing and authorized reservoirs in the Trinity River basin which were considered in the study are shown in Table IV-2, 12/ Appendix E.

Proposed Reservoirs

Several agencies have developed plans for the ultimate development of the surface water resource in the Trinity River basin. The locations of the 23 proposed reservoirs and 2 reservoir enlargements in the study area are shown in Figure IV-1. Of this number, 6 are outside the Trinity River basin. These are Humble, Honea, Dobbin, and Cleveland in the San Jacinto River basin, Cooper in the Sulphur River basin, and the enlargement of Blackburn Crossing in the Neches River basin. Here again, investigation of these six reservoirs was restricted to determination of terminal year yields and the demands on these yields as they affect interbasin transfer of water.

Present water quality within the basin, as previously described in the section on existing reservoirs, is also applicable to the proposed reservoir sites within the basin. Future water quality determinations were made and are fully described in Section VIII, Stream Quality Control, and Appendix C.

Pertinent data for the proposed reservoirs within the Trinity basin are shown in Table IV-3, 12/ Appendix E.

Ground Water

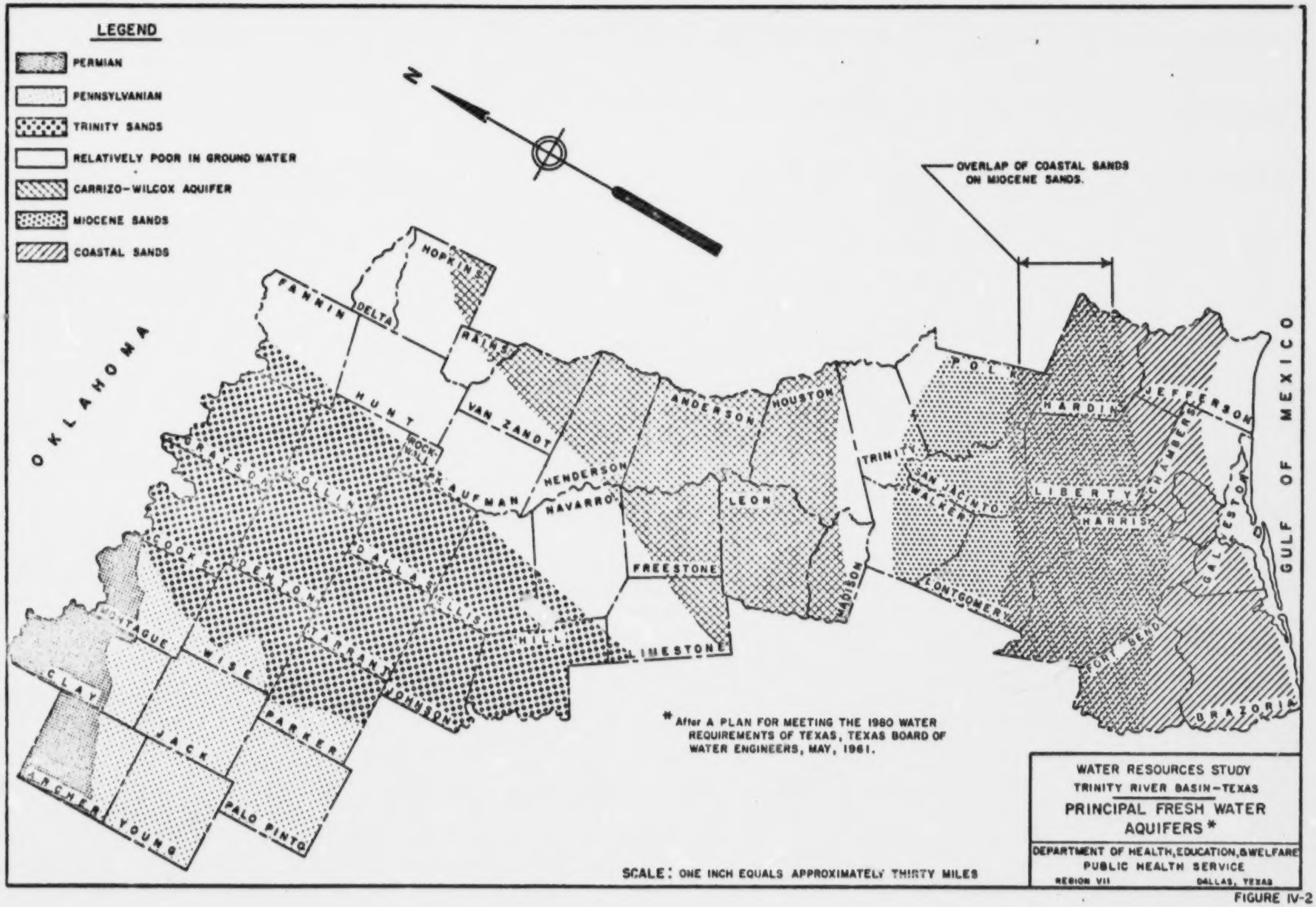
Studies of ground water conditions within the study area were made to determine the extent of present development and to estimate the capabilities of this resource for satisfaction of a portion of the future water requirement.

The principal fresh water aquifers present within the study area are shown on Figure IV-2. 14/

Reported use of ground water by aquifer is shown in Table IV-4, 3/ Appendix E. A more detailed list of the base year use is included in Table B-1, Appendix B.

To properly make estimates of future yields of ground water and aquifer conditions requires exhaustive and expensive field exploration and pumping tests. Practice has shown that even estimates made in this way are sometimes in error. Since the scope of this report warrants neither the time nor the expense involved in studies of this nature, estimates contained herein were made by a recognized consultant 15/ utilizing drillers' logs and drawdown curves from existing wells, certain broad assumptions as to the extent, thickness, transmissibility and permeability of the aquifers underlying the study area, and judgment based on long experience in this field.

A summary of his findings appear in Table IV-5, 15/ Appendix E. A description of conditions in each subarea is contained in Appendix B.


LEGEND
▨ PERMIAN
☐ PENNSYLVANIAN
▨ TRINITY SANDS
☐ RELATIVELY POOR IN GROUND WATER
▨ CARRIZO-WILCOX AQUIFER
▨ MIOCENE SANDS
▨ COASTAL SANDS
N
OKLAHOMA
GULF OF MEXICO
OVERLAP OF COASTAL SANDS ON MIOCENE SANDS.
FANNIN
DELTA
HOPKINS
RAINS
HUNT
VAN ZANDT
ROCKWALL
KAUFMAN
HENDERSON
NAVARRO
GRAYSON
COLLIN
COOKE
DENTON
DALLAS
ELLIS
HILL
TARRANT
JOHNSON
MONTAGUE
WISE
PARKER
CLAY
JACK
PALO PINTO
ARCHER
YOUNG
ANDERSON
HOUSTON
FREESTONE
LEON
LIMESTONE
MADISON
TRINITY
WALKER
SAN JACINTO
POLK
MONTGOMERY
HARDIN
LIBERTY
HARRIS
JEFFERSON
CHAMBERS
GALVESTON
FORT BEND
BRAZORIA

* After A PLAN FOR MEETING THE 1980 WATER REQUIREMENTS OF TEXAS, TEXAS BOARD OF WATER ENGINEERS, MAY, 1961.

SCALE: ONE INCH EQUALS APPROXIMATELY THIRTY MILES

WATER RESOURCES STUDY
TRINITY RIVER BASIN—TEXAS

PRINCIPAL FRESH WATER AQUIFERS*

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-2

V. ECONOMICS AND POPULATION

General

Economic analysis is indispensable to the planning of water resource development. The intent here is to examine all of the resources of the study area and to estimate the potential volume and nature of the economic activities that could develop. The study is made in two parts. A relatively detailed investigation is made to estimate growth to the year 2020, while a more general study of population only is used beyond 2020 to 2070.

Economic Base

The economic development of the study area depends on its competitive position in the Nation regarding raw materials, production and distribution advantages, and the character of its population. Since raw materials are an initial competitive factor, the appraisal of the study area's potential started with this situation. Such contributing factors as the proposed canal development, other distribution facilities, proximity to markets, population size, and particular labor skills, which indicate the extent of economic development over and above that based on raw materials, were also considered.

An examination of historical records of extractive, manufacturing, and service industries was made. Projections were then based on continuation of some of the past trends modified by changes expected in the historical pattern.

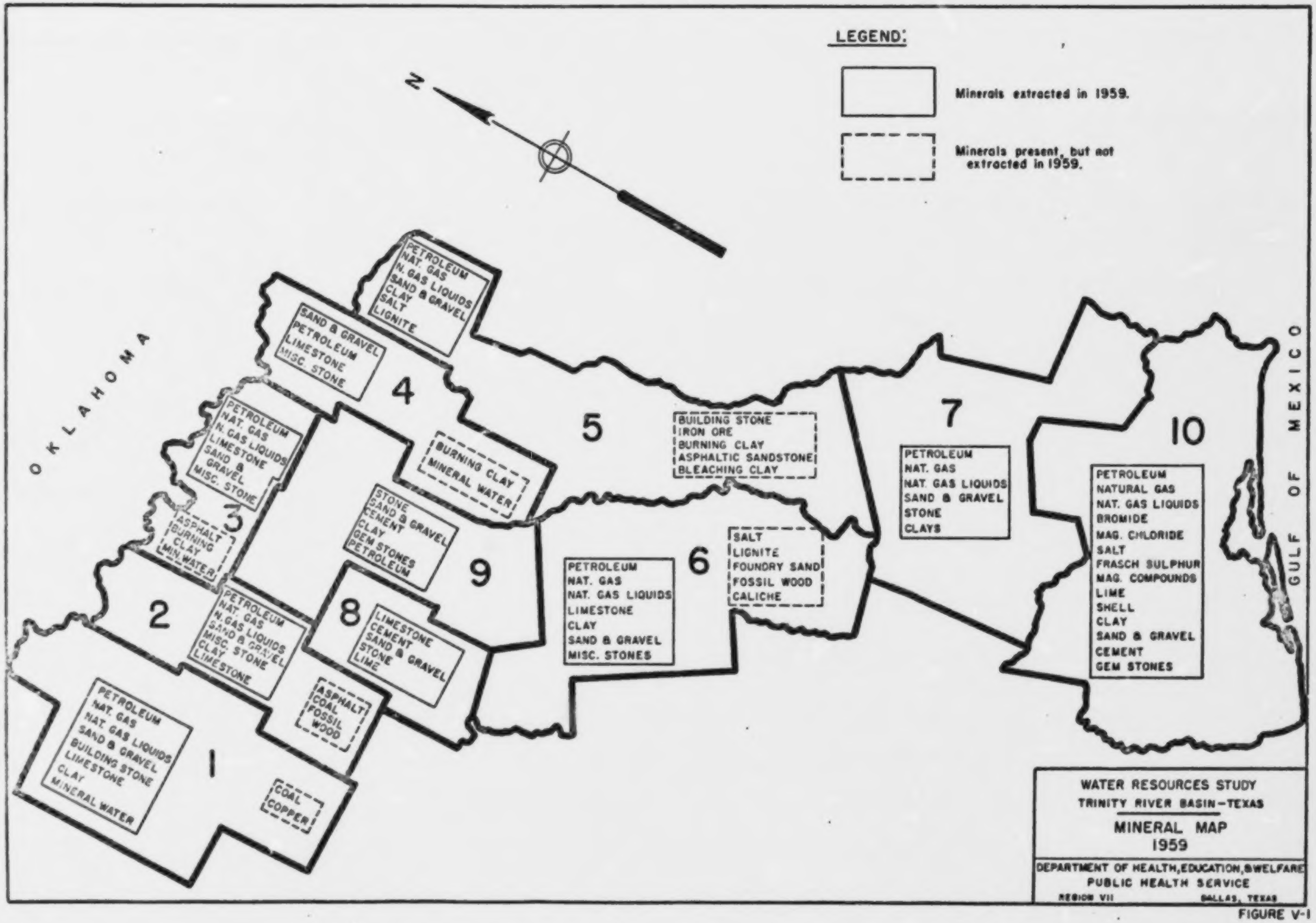
Extractive Industries

Minerals

The study area is rich in mineral deposits, which are not being utilized to their long-run potential at the present time. Only oil and gas, and to a lesser extent, stone, clay, and oystershell are being withdrawn from the majority of the total known deposits. Vast deposits of lignite, iron ore, salt, and sand and gravel remain as yet largely untapped. The existing mineral deposits are shown by subarea in Figure V-1. Estimated mineral reserves are shown in Table V-1. 28,29/

The value of mineral production for the area clearly shows the importance of this industry to the study area. It adds approximately $920 million annually to the national product as shown in Table V-2, 18/ and shows relatively little fluctuation between the years 1952 and 1959.

Employment in mineral extraction shows an upward trend between 1940 to 1960, increasing 155 percent from 18,034 to 45,909. The 1960 mining employment represents 2.8 percent of the study area's labor


LEGEND:
Minerals extracted in 1959.
Minerals present, but not extracted in 1959.
N
OKLAHOMA
GULF OF MEXICO
1
PETROLEUM
NAT. GAS
NAT. GAS LIQUIDS
SAND & GRAVEL
BUILDING STONE
LIMESTONE
CLAY
MINERAL WATER
COAL
COPPER
2
PETROLEUM
NAT. GAS
N. GAS LIQUIDS
SAND & GRAVEL
MISC. STONE
CLAY
LIMESTONE
ASPHALT
COAL
FOSSIL WOOD
3
PETROLEUM
NAT. GAS
N. GAS LIQUIDS
LIMESTONE
SAND & GRAVEL
MISC. STONE
ASPHALT
BURNING CLAY
MIN. WATER
4
PETROLEUM
NAT. GAS
N. GAS LIQUIDS
SAND & GRAVEL
CLAY
SALT
LIGNITE
SAND & GRAVEL
PETROLEUM
LIMESTONE
MISC. STONE
BURNING CLAY
MINERAL WATER
5
BUILDING STONE
IRON ORE
BURNING CLAY
ASPHALTIC SANDSTONE
BLEACHING CLAY
6
PETROLEUM
NAT. GAS
NAT. GAS LIQUIDS
LIMESTONE
CLAY
SAND & GRAVEL
MISC. STONES
SALT
LIGNITE
FOUNDRY SAND
FOSSIL WOOD
CALICHE
7
PETROLEUM
NAT. GAS
NAT. GAS LIQUIDS
SAND & GRAVEL
STONE
CLAYS
8
LIMESTONE
CEMENT
SAND & GRAVEL
STONE
LIME
9
STONE
SAND & GRAVEL
CEMENT
CLAY
GEM STONES
PETROLEUM
10
PETROLEUM
NATURAL GAS
NAT. GAS LIQUIDS
BROMIDE
MAG. CHLORIDE
SALT
FRASCH SULPHUR
MAG. COMPOUNDS
LIME
SHELL
CLAY
SAND & GRAVEL
CEMENT
GEM STONES

WATER RESOURCES STUDY
TRINITY RIVER BASIN–TEXAS

MINERAL MAP
1959

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-1

force compared to a national average of only 1.3 percent. Much of the employment increase was due to the expansion of this industry along the gulf coast during and following World War II. Continued expansion in the development of these resources is anticipated, especially in the middle and lower reaches of the Trinity River basin. The lignite deposits here are large and could furnish fuel for power to support growth of a large primary metals industry supplied by local as well as imported ores.

Table V-1

Estimated Mineral Reserves of the Study Area

Item	Amount
Petroleum	5 billion barrels (ultimate)
Gas	2010 production of 215 billion cubic feet
Stone and Oystershell	Sufficient for all foreseeable needs
Clay	2010 production of 2 million tons
Lignite	2 billion tons
Iron Ore	217 million tons
Salt	Unlimited
Sand and Gravel	2010 production of 20 million tons

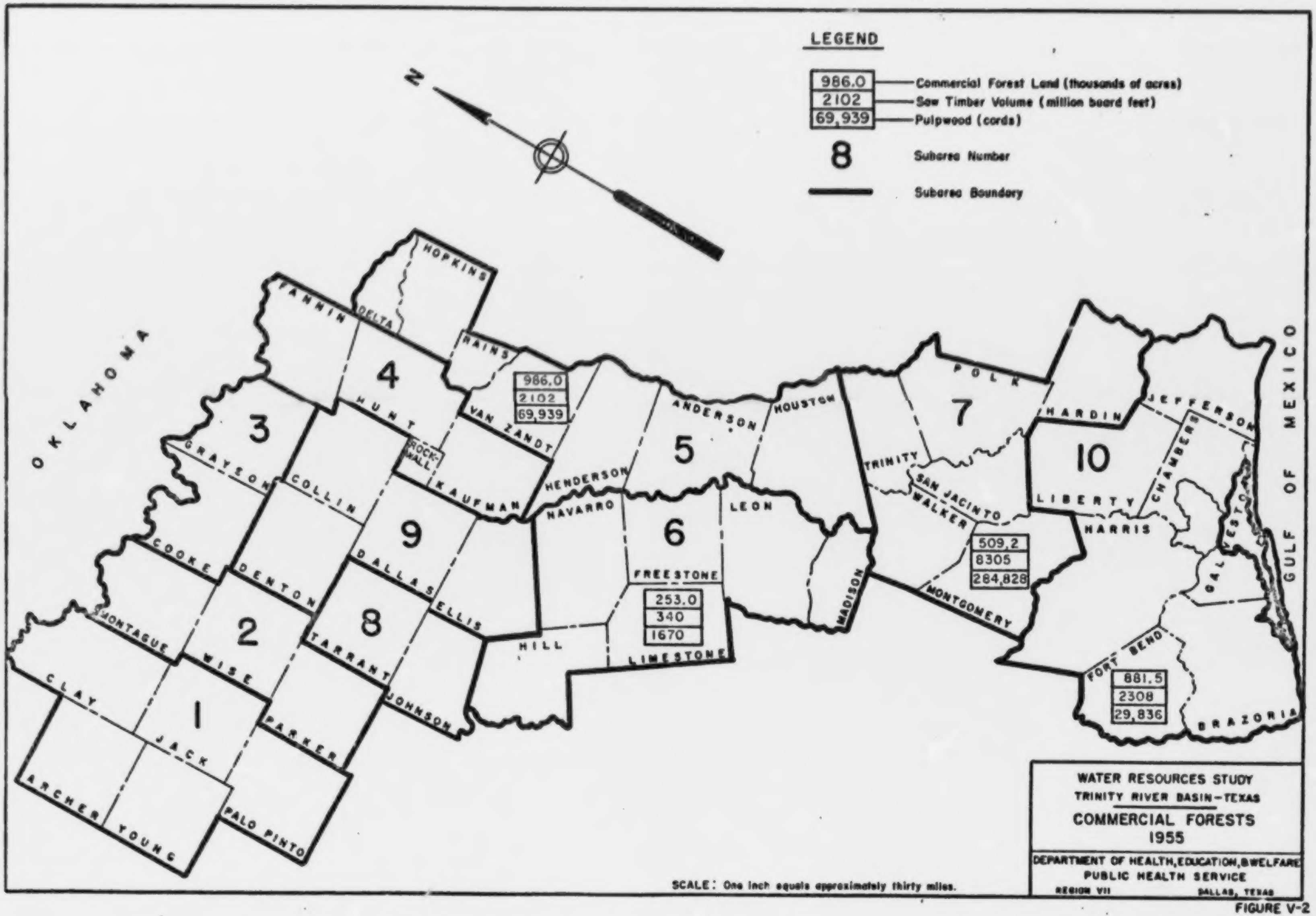
Table V-2

Value of Mineral Production, 1952-1959
(Figures in millions of 1958 dollars)

Subarea	1952	1953	1954	1955	1956	1957	1958	1959
1	85.1	90.0	91.4	96.1	93.5	87.4	83.7	81.6
2	33.9	36.3	35.7	32.5	31.5	36.5	46.1	47.8
3	34.2	43.3	49.3	55.7	58.6	56.3	51.5	53.6
4	4.1	4.9	7.8	5.0	4.8	3.4	2.8	2.7
5	68.1	67.5	65.2	72.0	70.8	70.0	56.4	56.0
6	7.7	11.0	14.2	16.0	15.4	15.0	13.6	14.1
7	88.1	91.7	89.7	100.5	93.2	83.7	62.1	68.9
8	7.0	6.9	8.6	9.8	10.5	8.9	13.3	13.8
9	14.3	13.6	21.0	24.4	21.9	18.9	24.1	24.5
10	494.1	526.1	551.5	632.3	625.7	556.1	506.3	477.3
TOTAL	836.6	891.3	934.4	1,044.3	1,025.9	936.2	859.9	840.3

Forests

The commercial forests of the study area are confined to 16 of the 26 counties in Subareas 5, 6, 7, and 10 as shown in Figure V-2. Out of 4,885,000 acres of commercial forest land in 1955, the growing stock is estimated to total 3,440 million cubic feet of which approximately 56 percent is in softwoods and the remainder in hardwoods.


LEGEND
986.0 Commercial Forest Land (thousands of acres)
2102 Saw Timber Volume (million board feet)
69,939 Pulpwood (cords)
8 Subarea Number
Subarea Boundary
N
OKLAHOMA
GULF OF MEXICO
1
2
3
4
5
6
7
8
9
10
CLAY
JACK
ARCHER
YOUNG
PALO PINTO
PARKER
MONTAGUE
WISE
COOKE
DENTON
GRAYSON
COLLIN
FANNIN
DELTA
HOPKINS
HUNT
RAINS
ROCK-WALL
KAUFMAN
VAN ZANDT
DALLAS
ELLIS
TARRANT
JOHNSON
HILL
NAVARRO
HENDERSON
ANDERSON
FREESTONE
LIMESTONE
LEON
HOUSTON
MADISON
TRINITY
POLK
SAN JACINTO
WALKER
MONTGOMERY
HARDIN
LIBERTY
JEFFERSON
CHAMBERS
HARRIS
GALVESTON
FORT BEND
BRAZORIA
986.0
2102
69,939
253.0
340
1670
509.2
8305
284,828
881.5
2308
29,836

WATER RESOURCES STUDY
TRINITY RIVER BASIN—TEXAS
COMMERCIAL FORESTS
1955
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

SCALE: One inch equals approximately thirty miles.

FIGURE V-2

The volume of sawtimber totals approximately 13,000 million board feet as shown in Table V-3 19/ below.

Table V-3

Forest Resources, 1953-19

Subarea	Acreage in Commercial Forests	Sawtimber Volume (Million Board Feet)	Growing Stock (Million Cubic Feet)	1955 Pulpwood Production (Cords)
5	986,000	2,102	565.5	69,937
6	253,000	340	120.5	1,670
7	2,764,500	8,305	2,108.3	284,828
10	881,500	2,308	649.2	79,836
TOTAL	4,885,000	13,055	3,443.5	436,271

A large variety of forestry products are presently made. These include furniture, lumber, containers, toys, cedar oil, newsprint, and many others.

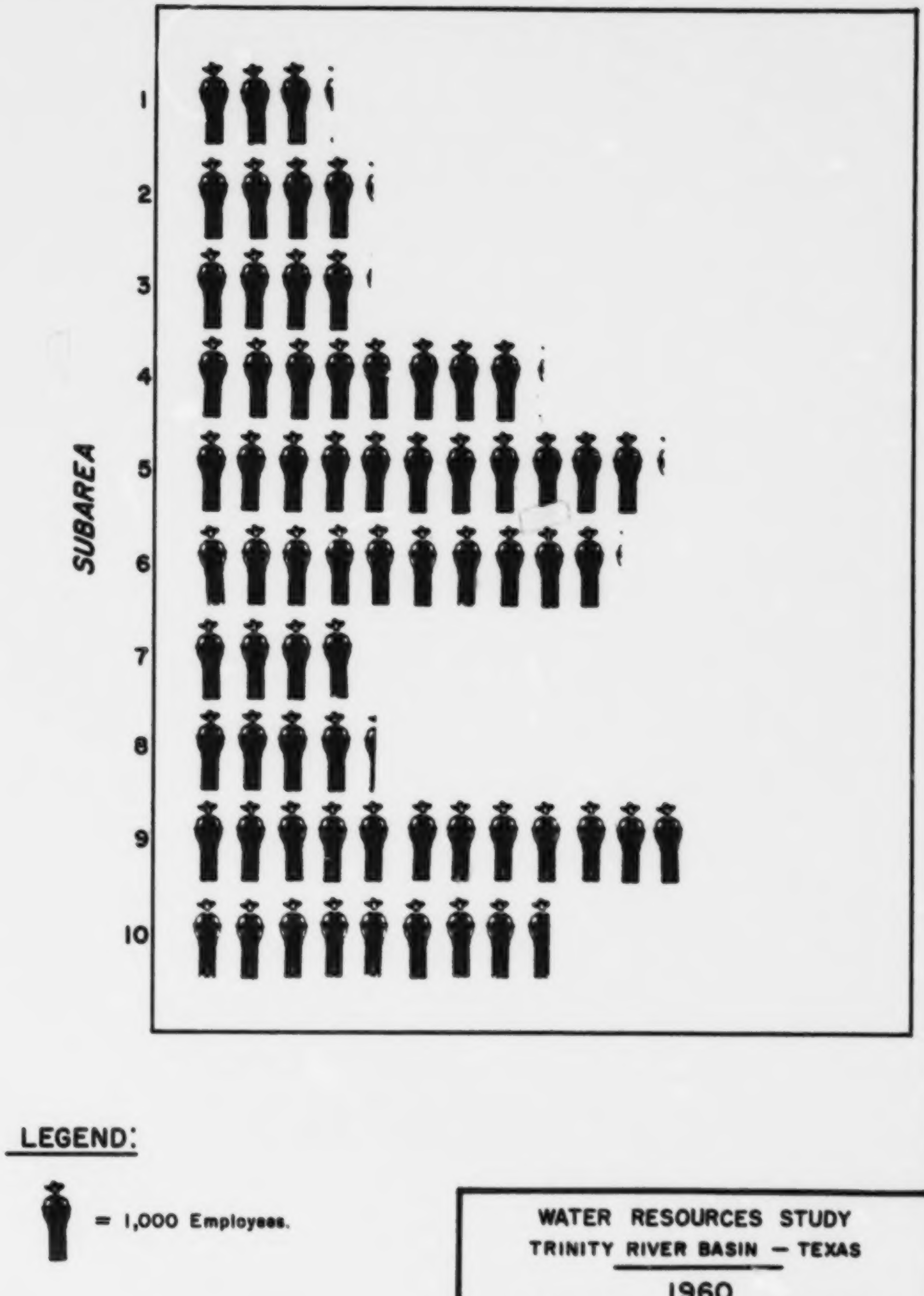
Employment in industries associated with the forest resource was about 15,800 in 1960 - not nearly the maximum attainable on a sustained basis. Recent records show that only 52 percent of the net annual growth is being cut.

Between 1935 and 1954, the forest area has increased 9 percent due to the abandonment of submarginal farm land. Over a long period of time, however, the commercial forest acreage is expected to remain relatively constant, as gains of additional land will be offset by loss of present forest land to urban developments and their appurtenances. More effective management and use of available acreage could increase the growing stock from 700 cubic feet per acre at present to about 2,000 cubic feet per acre.

Agriculture

Although agriculture in the Nation as well as in the study area has been experiencing a long-term decline, it is still a large water consumer and certainly will continue as such in the future. In addition, agricultural workers are an influence on the total employment pattern. Service employment opportunities depend in part on these workers and their incomes.

In terms of employment, agriculture, the largest single employer in the study area in 1940 with 183,000 workers, accounted for 18.7 percent of the total labor force. In 1960, the number employed in agriculture dwindled to 70,000, or only 4.3 percent of the labor force, distributed as shown in Figure V-3. The entire



WATER RESOURCES STUDY
TRINITY RIVER BASIN — TEXAS

1960
AGRICULTURAL EMPLOYMENT

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-3

study area experienced a decreasing nonmunicipal population which is the main source of agricultural workers. The nonmetropolitan portion of the study area (Subareas 1 through 7) incurred a nonmunicipal population loss of 49.4 percent between 1940 and 1960 while the loss in the metropolitan portion (Subareas 8 through 10) was 30.2 percent.

Of more significance is the ratio of the decrease in agricultural employment to the decrease in nonmunicipal population. This ratio is 0.2 in the metropolitan subareas and 0.3 in the nonmetropolitan subareas, indicating that the greatest shift away from farming is occurring in the presently agricultural portion of the study area. This is due primarily to mechanization in agriculture, the growth of other industry in heretofore agricultural communities, and the greater income security offered to the potential farmer by these industries.

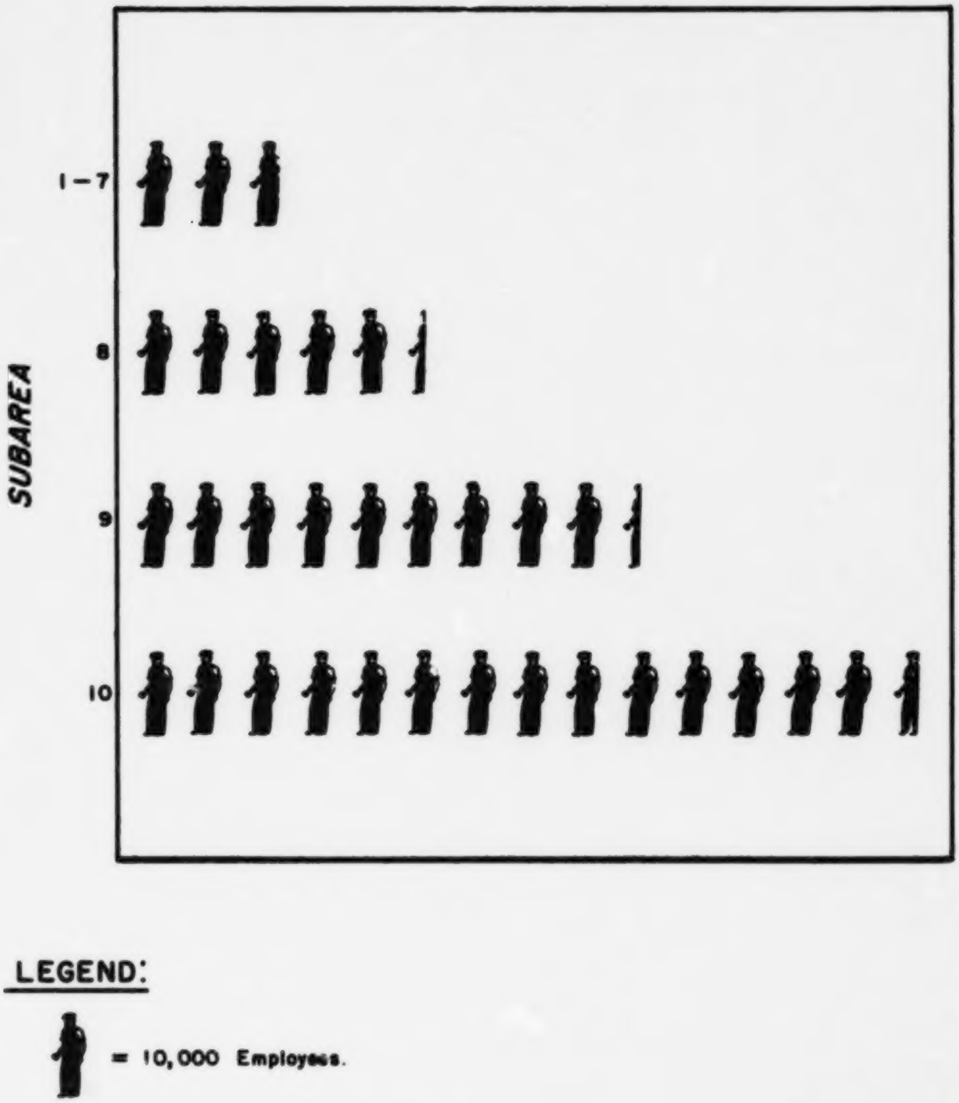
Agricultural statistics for the study area by subareas are shown in Table V-4, 20/ Appendix E. For the period 1944 to 1959, the study area showed a 46.2 percent decline in the number of farms but only a 33.5 percent decline in the cropland harvested. This indicates a shift to larger farms of which there is also nationwide evidence. On the other hand, the value of crops sold and the value of livestock and livestock products sold showed gains of 10.7 percent and 1.8 percent, respectively, between 1944 and 1954.

Manufacturing

Manufacturing employment in the study area increased 157 percent in the two decades from 1940 to 1960, compared to a nationwide increase of only 52 percent. For the same period, that portion of the labor force employed in this category was increasing at an annual rate of 2-3/16 percent in the study area and only 1-1/8 percent in the Nation. Notwithstanding the greater rate of increase in the study area, the percent of the labor force in manufacturing is still 5 percent under the national average. This accelerated growth of manufacturing in recent years is characteristic of many parts of the southwestern states, which before World War II engaged principally in the extraction and primary processing of raw materials.

The distribution of the manufacturing labor force, as shown in Table V-5 and Figure V-4, reveals some differences from the Nation as a whole.

Examination of the table shows the study area to be well ahead of the Nation in the percentage of the manufacturing labor force in the category of "Other Nondurables." This group consists of petroleum refining, paper and allied products, and rubber and leather products. The predominance of petroleum refining along the gulf coast is the primary reason for the high ratio in this industry group. The ratio of 1.6 shown for chemicals and allied products is



WATER RESOURCES STUDY
TRINITY RIVER BASIN — TEXAS

1960
MANUFACTURING EMPLOYMENT

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-4

also due to high concentrations of this industry in the gulf region. Food and kindred products manufacturing is fairly evenly distributed throughout the study area, employing 13.1 percent of the manufacturing labor force, compared to only 9.2 percent for the Nation. On the other hand, the ratios of 0.5 for primary metals and textiles and apparel suggest possibilities for considerable expansion in these industries in light of a continuing trend toward diversification.

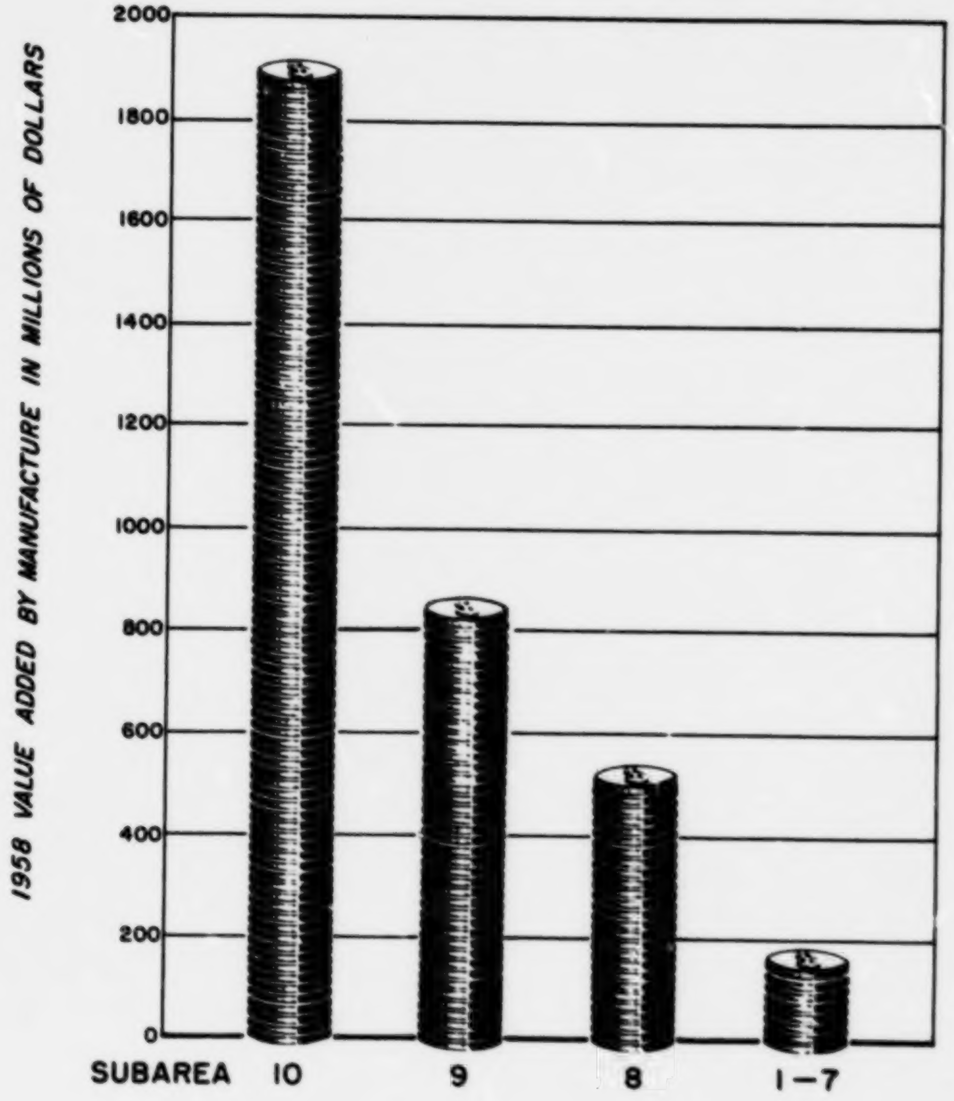
Table V-5

Percentage Distribution of the Manufacturing Labor Force Among the Industry Groups Analyzed
1960

Item	Study Area	United States	Ratio of Study Area to U. S.
Total Manufacturing	100.0	100.0	1.0
Resource Oriented	48.4	40.3	1.2
Furniture, Lumber, & Wood Products	4.9	6.4	0.8
Primary Metals	3.4	7.3	0.5
Food & Kindred Products	13.1	9.2	1.4
Chemicals & Allied Products	8.9	5.5	1.6
Stone, Clay, & Glass	3.4	3.4	1.0
Other Nondurables	14.7	8.5	1.7
Nonresource Oriented	51.6	59.7	0.9
Fabricated Metals, Machinery, Transportation, & Other Durable Goods	37.7	37.5	1.0
Textiles and Apparel	7.4	13.5	0.5
Printing and Publishing and Not Elsewhere Classified	6.5	8.7	0.7

A trend toward a balanced manufacturing base is evident in the study area as shown in Table V-6,8,9,20,30/ Appendix E. An over-all increase in manufacturing employment has prevailed in the nonmetropolitan areas of the study area as well as in the larger cities. The 1960 distribution of manufacturing employees by subarea is shown in Figure V-4.

The value added by manufacture in the study area increased 117 percent during the period 1947-1958, while the same period increase in employment was only 62 percent, resulting in an increase in value added per employee. These statistics for the subareas are shown in Table V-7 9/ and Figure V-5. The nonmetropolitan subareas experienced less than half the percentage growth of the metropolitan portion of the study area.



WATER RESOURCES STUDY
TRINITY RIVER BASIN — TEXAS

1958 VALUE ADDED BY MANUFACTURE

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-5

Generally, increase in employment, coupled with increased value added per employee, reflects favorably on the prospect for continued growth in the manufacturing industry.

Table V-7

Value Added by Manufacture*
1947-1958
(Values in Constant 1958 Dollars)

Subarea	1947 ($1,000)	1958 ($1,000)	% Change in Value Added 1947-1958	% Change in Employment 1947-1958
1	3,748	5,500	47	29
2	4,427	9,103	106	55
3	31,871	47,006	47	80
4	11,292	29,982	166	128
5	10,249	17,888	75	7
6	10,476	16,775	60	23
7	24,196	17,246	-29	-30
Subtotal - Nonmetropolitan	96,259	143,500	49	30
8	194,961	523,283	168	71
9	334,593	844,821	152	116
10	844,237	1,685,425	100	42
Subtotal - Metropolitan	1,373,791	3,053,529	122	66
Total Study Area	1,470,050	3,197,029	117	62

* Includes only those counties for which data are available for the three years of 1947, 1954, and 1958.

Service Industries

Service industries constitute a large segment of the economic activity of the study area. They employed 55 percent and 70 percent of the total labor force in 1940 and 1960, respectively, as indicated in Table V-6. The national increase for these industries was from 64 to 68 percent during the same two decades. The higher 1960 percentage in the study area is due to relatively more employees in government, finance, and insurance.

Service industry employment varies with urbanization, population density, and income levels. The ratio of this employment to the total labor force can be determined and projections made on the basis of expected changes.

Population

The population of the study area was 4,077,896 in 1960. This is an increase of 181 percent since 1910 compared to the same period increase of 94 percent for the conterminous United States. All of the growth was confined to the three metropolitan subareas which increased 424 percent while the nonmetropolitan subareas population showed a 20 percent decline. The decrease in agricultural employment and the accompanying increase in manufacturing employment and associated service industries between 1940 and 1960 are the primary reasons for these population trends.

The historical populations are summarized in Table V-8, [8] Appendix E, and a map of the 1960 population distribution is shown in Figure V-6.

Future Growth

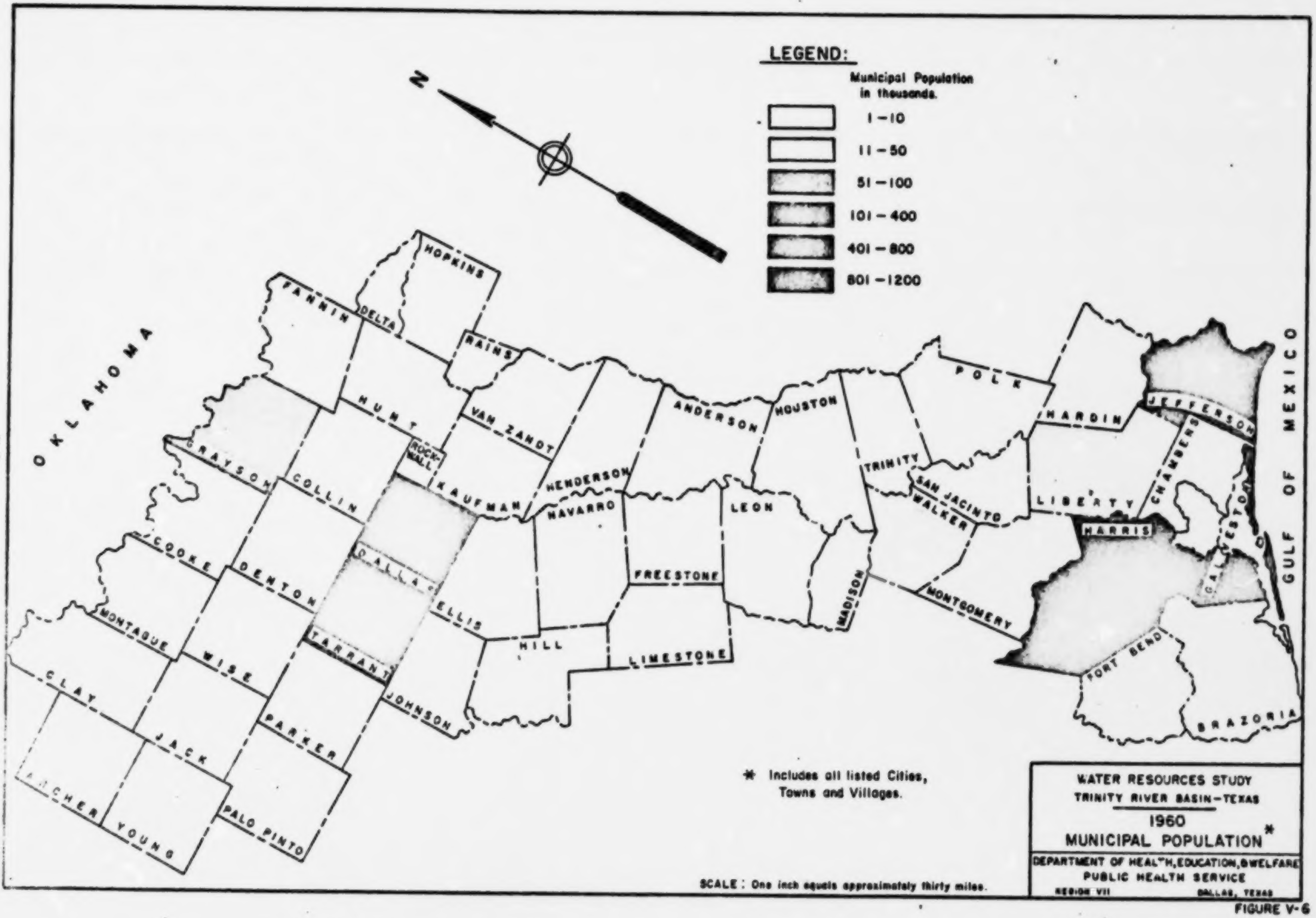
Economic Projections

The Trinity River basin and surrounding counties which comprise the study area are endowed with many factors which can be expected to promote economic growth. Transportation, raw materials, fuel, power, adequate labor supply, and climate are some of the most important. A discussion of these and other attributes follows.

The minerals industry, which is presently very active, has good promise for expansion. A large variety of mineral deposits, many as yet untapped, are present. These include petroleum, natural gas, asphalt, lignite, limestone, sand and gravel, sulphur, salt, clays, iron ore, copper, and many others as shown in Figure V-1 and Table V-1. The largest expansion is expected to be in the mining of iron ore for local processing, and of lignite for fuel to produce the electric power necessary for the reduction of local as well as imported ores. With a favorable market and the transportation facility provided by the proposed navigation canal, employment in the mineral industries is expected to increase 67 percent, from 45,900 in 1960 to 76,700 in 2020.

A part of the projected national increase in the demand for timber and forest products will be satisfied by these resources of the study area. The present production rate is only 52 percent of the net annual growth which can be expected to improve with good forestry management practices. Employment in forestry can, therefore, be expected to increase from approximately 1,400 in 1960 to 27,000 by the year 2020.

The study area contains some of the best agricultural lands in the State of Texas. Although employment, acres of cropland harvested, and the number of farms have been decreasing, production,


LEGEND:
Municipal Population in thousands.
1-10
11-50
51-100
101-400
401-800
801-1200
N
OKLAHOMA
GULF OF MEXICO
HOPKINS
FANNIN
DELTA
RAINS
HUNT
ROCK-WALL
VAN ZANDT
GRAYSON
COLLIN
KAUFMAN
HENDERSON
ANDERSON
HOUSTON
TRINITY
POLK
HARDIN
JEFFERSON
CHAMBERS
LIBERTY
SAN JACINTO
WALKER
LEON
NAVARRO
COOKE
DENTON
DALLAS
ELLIS
FREESTONE
MADISON
MONTGOMERY
HARRIS
GALVESTON
FORT BEND
BRAZORIA
MONTAGUE
WISE
TARRANT
HILL
LIMESTONE
CLAY
JACK
PARKER
JOHNSON
ARCHER
YOUNG
PALO PINTO

* Includes all listed Cities, Towns and Villages.

SCALE: One inch equals approximately thirty miles.

WATER RESOURCES STUDY
TRINITY RIVER BASIN-TEXAS
1960
MUNICIPAL POPULATION*
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-6

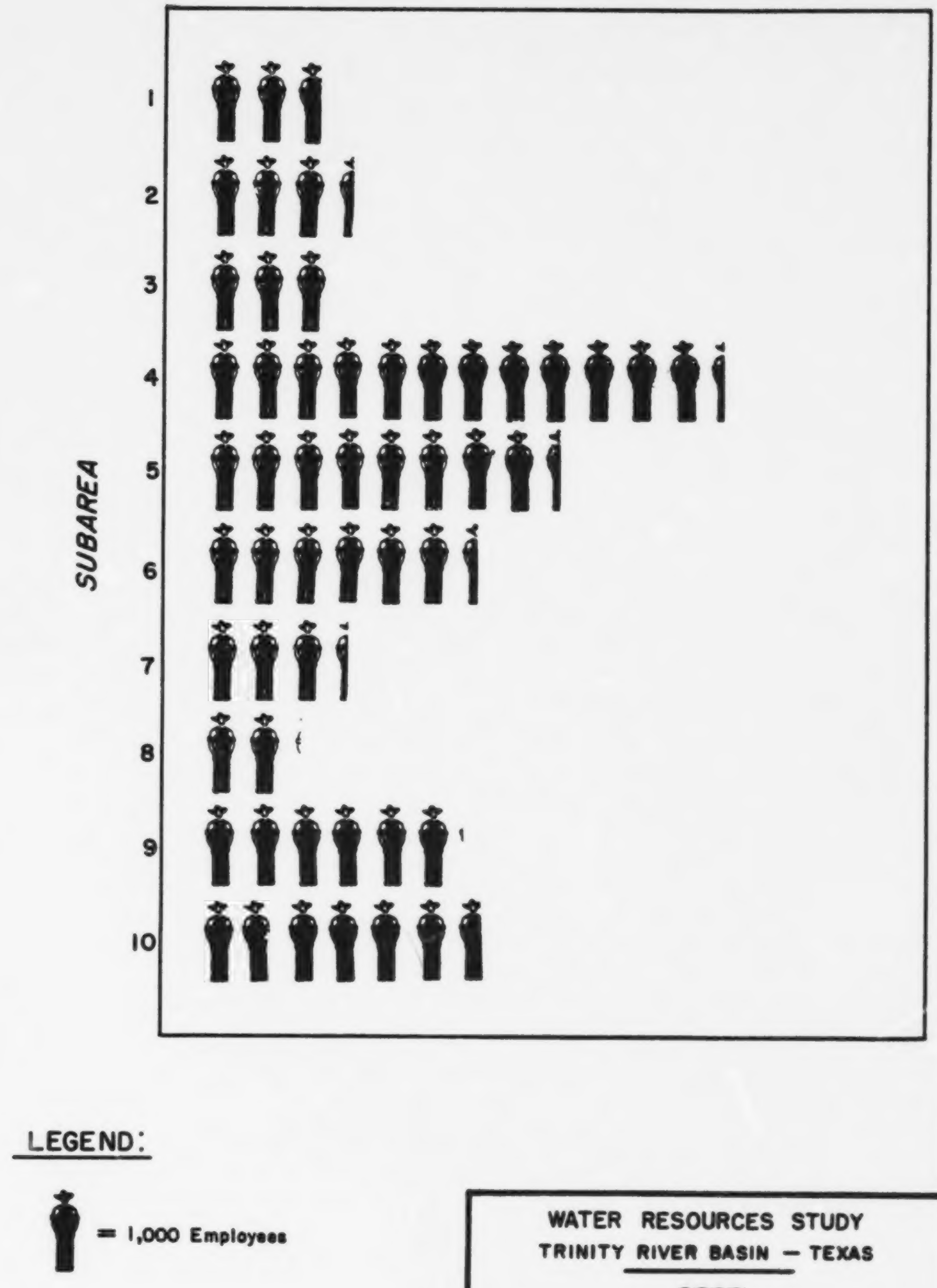
as reflected by the constant dollar value of crops and livestock sold, has shown a slight increase. Agricultural production is expected to continue upward in step with the demand for food and fiber created by a growing population. Therefore, farm production by the year 2020 is expected to increase by a factor of 2.4 with a concurrent employment drop of 21 percent. The expected 2020 distribution of agricultural employment is shown in Figure V-7.

The resource-oriented manufacturing industries are expected to form an important part of the future economic base of the study area. Significant expansion is expected in primary metals; chemical; petroleum and gas; pulp and paper; food processing; lumber and wood products; and stone, clay, and glass products. Besides the impetus for growth provided by the local availability of raw materials, upon which these industries rely, there is the additional factor of distribution advantage, the attractiveness of which will be enhanced tremendously by the proposed navigation facility. Accordingly, employment in the resource-oriented industries can be expected to increase from 156,563 in 1960 to over 531,000 by 2020.

The nonresource-oriented industries are also expected to increase significantly. These manufacturers regard market, transportation, and labor among the most important factors in selecting plant locations. Fabricated metals, machinery, transportation equipment, apparel, and other durable goods are examples of this type of manufacture. Present development of these industries is extensive in the three metropolitan subareas, but very small in the rest of the study area. Since many of these industries depend on import of materials, the proposed canalization of the Trinity River will increase the competitive advantage of the area to attract more of these manufacturers and create a situation favoring the expansion of those presently existing. The projected 1960 - 2020 increase of employment in these industries is 184 percent from a 1960 base of 166,891.

That portion of the labor force to be engaged in manufacturing in the metropolitan subareas by the year 2020 was assumed to approach the 20 percent that presently exists in industrial cities of the south-central states. In the remainder of the area, the projected manufacturing labor force was based on the resource potential of the area for resource-oriented industries and on past trends for other manufacturing employment. The subarea distribution of manufacturing employment expected in 2020 is shown in Figure V-8.

The proportional increase of employment in the service industries will vary among areas depending on relative growth, income and cultural norms. The predicted number of service workers is based on past national trends modified by the above factors. Projected employment in the service industries is 3,347,000 in 2020 compared to 1,114,000 in 1960.

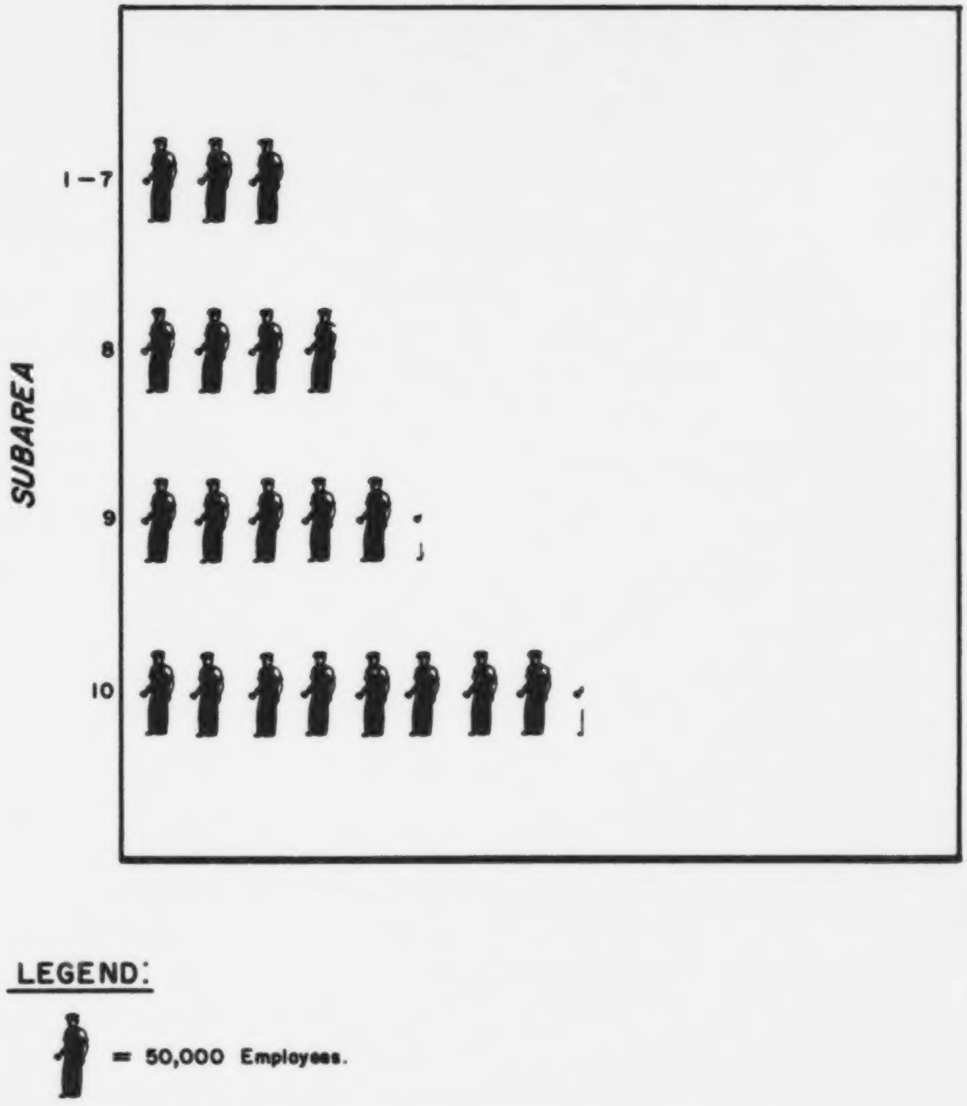


WATER RESOURCES STUDY
TRINITY RIVER BASIN — TEXAS

2020
AGRICULTURAL EMPLOYMENT

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-7



WATER RESOURCES STUDY
TRINITY RIVER BASIN — TEXAS

2020
MANUFACTURING EMPLOYMENT

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-8

Table V-9

Projected 2020 Percentage Employment Distribution

	Total Study Area	Metropolitan Subareas 8 through 10	Nonmetropolitan Subareas 1 through 7
Agriculture	1.2	0.4	6.6
Forestry & Fisheries	0.6	0.6	0.2
Mining	1.6	1.7	1.6
Manufacturing	21.4	21.0	23.6
Resource Oriented	11.3	10.7	15.2
Furniture, Lumber & Wood Products	1.1	0.9	2.0
Primary Metals	1.3	1.1	2.6
Food and Kindred Products	2.2	2.2	2.3
Chemicals and Allied Products	3.1	3.1	3.6
Stone, Clay, & Glass Products	0.9	0.8	1.3
Other Nondurable Goods	2.7	2.6	3.4
Nonresource Oriented	10.1	10.3	8.4
Fabricated Metals, etc. [a]	6.9	7.2	4.4
Apparel and Textiles	1.9	1.8	3.2
Printing, Publishing, NEC	1.3	1.3	0.8
Basic Industries	24.8	23.7	32.0
Service Industries	71.2	72.3	64.0
Unemployed	4.0	4.0	4.0
Labor Force	100.0	100.0	100.0
Number of Workers (in thousands)	4,699.1	4,080.4	618.7

---

[a] Includes Fabricated Metals, Machinery, Electrical Equipment, Transportation Equipment, and Other Durable Goods.

The preceding analysis was the basis of projecting total employment in 2020. To establish the total labor force, an assumed unemployment of 4 percent was added. The percent distribution of the labor force for the study area is shown in Table V-9. No employment analysis was made for the year 2070.

Population Projections

Many factors were considered in formulating the population projections of the municipal and nonmunicipal components.* The factors used to determine the municipal and nonmunicipal parts of the projected population include: (1) resources and employment analysis; (2) the national trend toward urbanization; (3) growth comparisons with cities that were of similar size to the cities of the study area in the past; and (4) the ratio of growth between study area cities and the national urban population as defined herein. Comparison with projections made by the U. S. Army Engineer District, Fort Worth, showed very close agreement; therefore, in the interest of uniformity, a single projected population mutually acceptable to both agencies was developed and is presented in Table V-10.

Table V-10

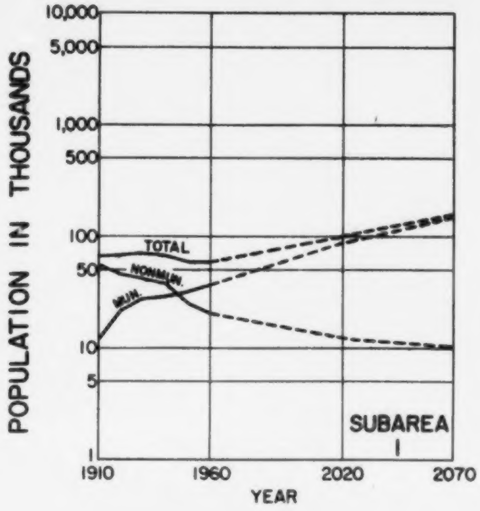
Population Projections, By Subareas
1960, 2020, and 2070

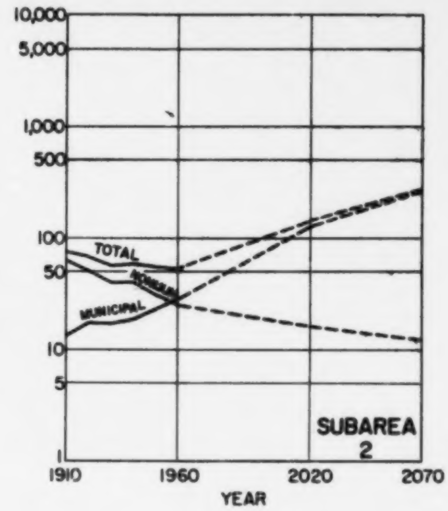
Subarea	1960	2020	2070
1	59,649	100,900	160,000
2	54,785	148,100	281,700
3	95,603	313,800	627,600
4	99,088	304,200	575,300
5	115,862	220,400	350,000
6	107,711	203,900	325,000
7	100,496	328,400	614,500
8	573,215	2,264,800	4,246,600
9	1,083,601	3,198,700	6,000,800
10	1,787,886	5,258,100	9,853,000
Total	4,077,896	12,341,300	23,034,500

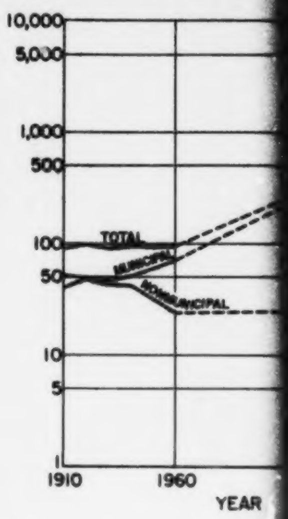
In the subareas where present nonmunicipal population is a significant part of the total, the municipal segment is expected to gain, while the nonmunicipal population continued to decrease between 1960 and 2020. After the year 2020, the nonmunicipal population will probably remain essentially stationary. The projections of total, municipal, and nonmunicipal population by subarea are graphically presented in Figure V-9.

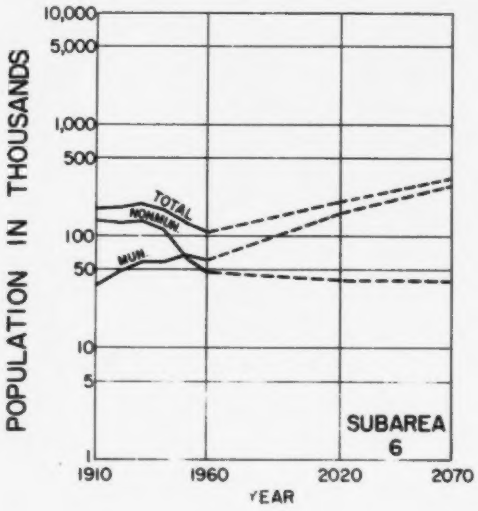
---

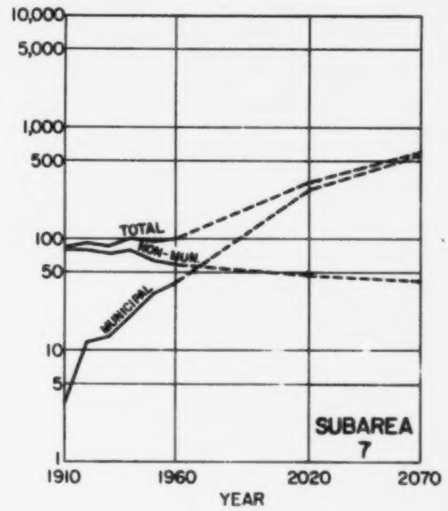
* Municipal is defined here as including the population of all places of 1,000 or more persons, and nonmunicipal is the classification used for the remainder of the population.

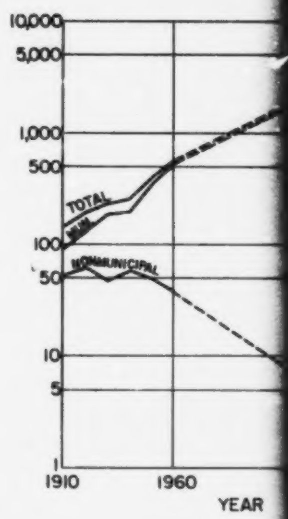

POPULATION IN THOUSANDS
10,000
5,000
1,000
500
100
50
10
5
1
TOTAL
NONMUN.
MUN.
SUBAREA
1
1910
1960
2020
2070
YEAR

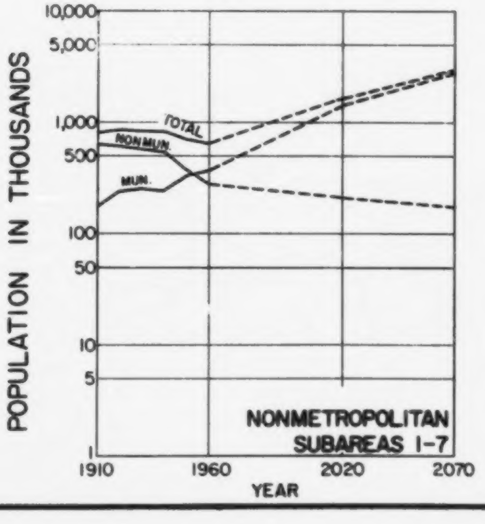

10,000
5,000
1,000
500
100
50
10
5
1
TOTAL
NONMUN.
MUNICIPAL
SUBAREA
2
1910
1960
2020
2070
YEAR

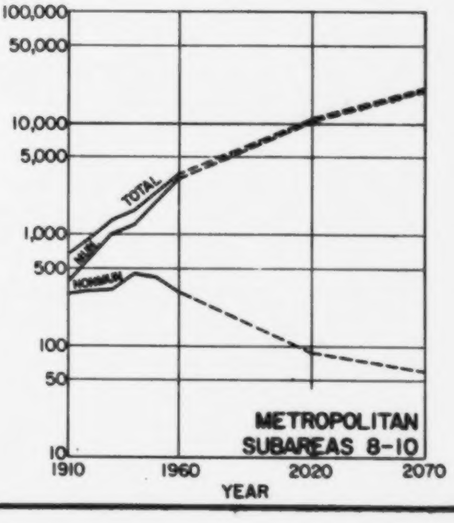

10,000
5,000
1,000
500
100
50
10
5
1
TOTAL
MUNICIPAL
NONMUNICIPAL
1910
1960
YEAR

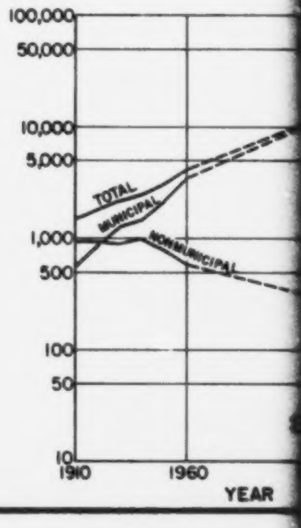

POPULATION IN THOUSANDS
10,000
5,000
1,000
500
100
50
10
5
1
TOTAL
NONMUN.
MUN.
SUBAREA
6
1910
1960
2020
2070
YEAR

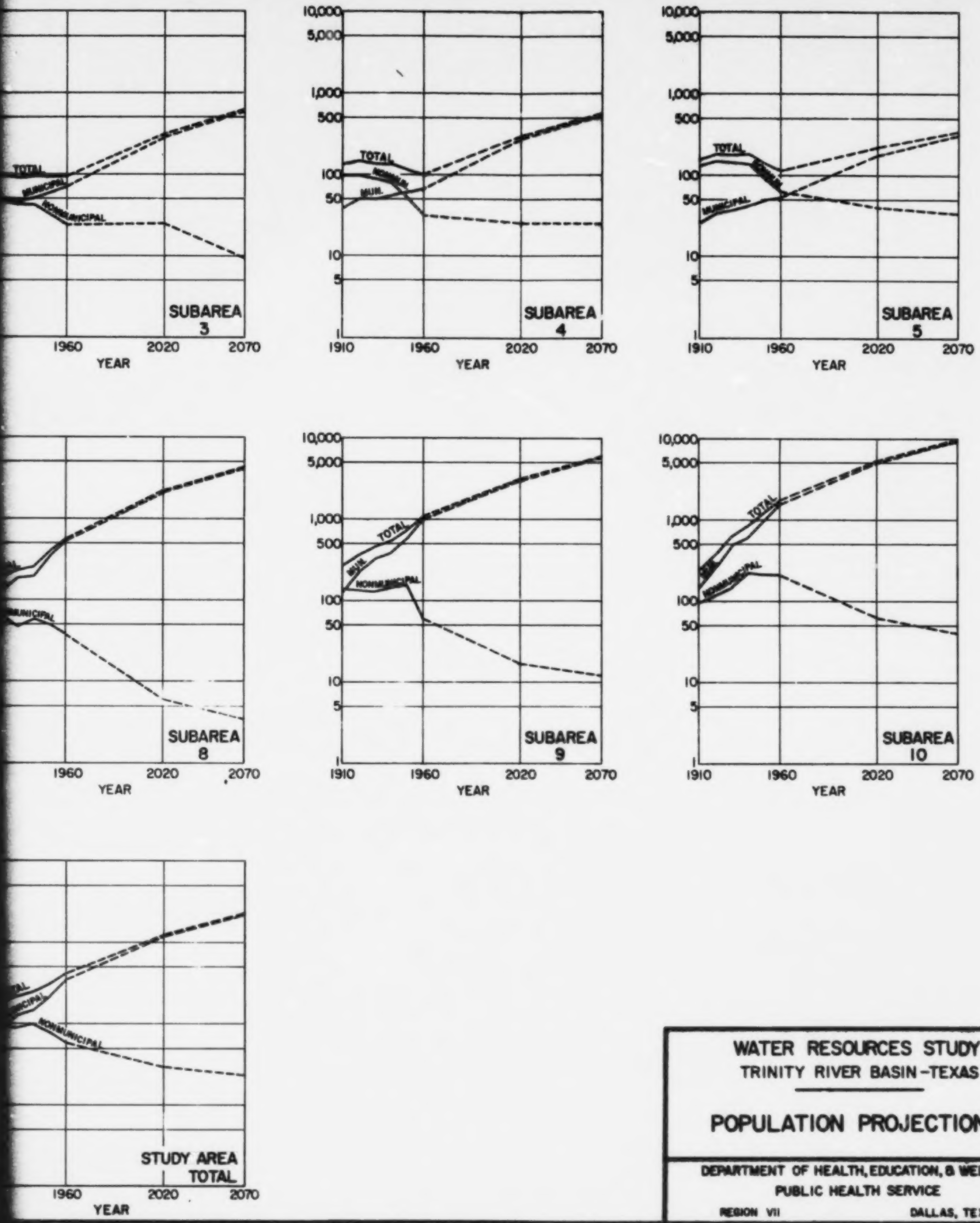

10,000
5,000
1,000
500
100
50
10
5
1
TOTAL
NON-MUN.
MUNICIPAL
SUBAREA
7
1910
1960
2020
2070
YEAR


10,000
5,000
1,000
500
100
50
10
5
1
TOTAL
MUN.
NONMUNICIPAL
1910
1960
YEAR


POPULATION IN THOUSANDS
10,000
5,000
1,000
500
100
50
10
5
1
TOTAL
NONMUN.
MUN.
NONMETROPOLITAN
SUBAREAS 1-7
1910
1960
2020
2070
YEAR


100,000
50,000
10,000
5,000
1,000
500
100
50
10
TOTAL
MUN.
NONMUN.
METROPOLITAN
SUBAREAS 8-10
1910
1960
2020
2070
YEAR


100,000
50,000
10,000
5,000
1,000
500
100
50
10
TOTAL
MUNICIPAL
NONMUNICIPAL
1910
1960
YEAR



WATER RESOURCES STUDY
TRINITY RIVER BASIN-TEXAS

POPULATION PROJECTIONS

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE V-9

VI. WATER REQUIREMENTS

General

The term "water requirements," as applied to an area the size of the Trinity River basin, encompasses a multiplicity of uses which are dependent upon a large number of variables. Although primarily concerned with municipal and industrial water use, this study examines all of the consumptive uses of water as they affect the supply and demand for water within the basin. Historical as well as projected water requirements for irrigation uses were determined by others. 12/

Determination of Water Use

In general, average daily total water use was determined for each county within the study area from past records of municipalities and industries. These values are then reduced to unit uses, trended, projected, and translated into total water requirement taking into account the several modifying factors thought to exert an influence on the amount of water used. The sources of data, methods used, and the rationale for using them are fully described in Appendix A.

Base Year Water Use

The year 1958 was selected as a base for the study because it was the most recent year for which data were available from several reliable sources. Tables A-1 and A-2 in Appendix A show the municipal and industrial unit water uses by county for the study area.

The 1958 municipal and industrial water use in mgd by subarea, type of use, and source is shown in Table VI-1. 1,2,3,4,5,6/

Table VI-1

Base Year Water Use

	1958 Water Use in MGD				
	Total*			Source	
Subarea	M. & I.	Municipal	Industrial*	Surface	Ground
1	4.630	3.829	0.801	4.532	0.098
2	3.384	2.279	1.105	1.518	1.866
3	13.559	10.212	3.347	6.527	7.032
4	7.424	5.887	1.537	5.682	1.742
5	11.179	5.358	5.821	6.516	4.663
6	9.560	5.295	4.265	6.509	3.051
7	13.254	4.916	8.338	7.437	5.817
8	71.668	57.688	13.980	55.199	16.469
9	135.634	117.531	18.103	113.285	22.349
10	681.690	165.539	516.151	405.328	276.362
Study Area	951.982	378.534	573.448	612.533	339.449

* Including consumptive use for thermal power generation.

Dividing the total municipal and industrial water use by the estimated 1958 municipal population gives an over-all use of 293 gallons per capita day in the base year.

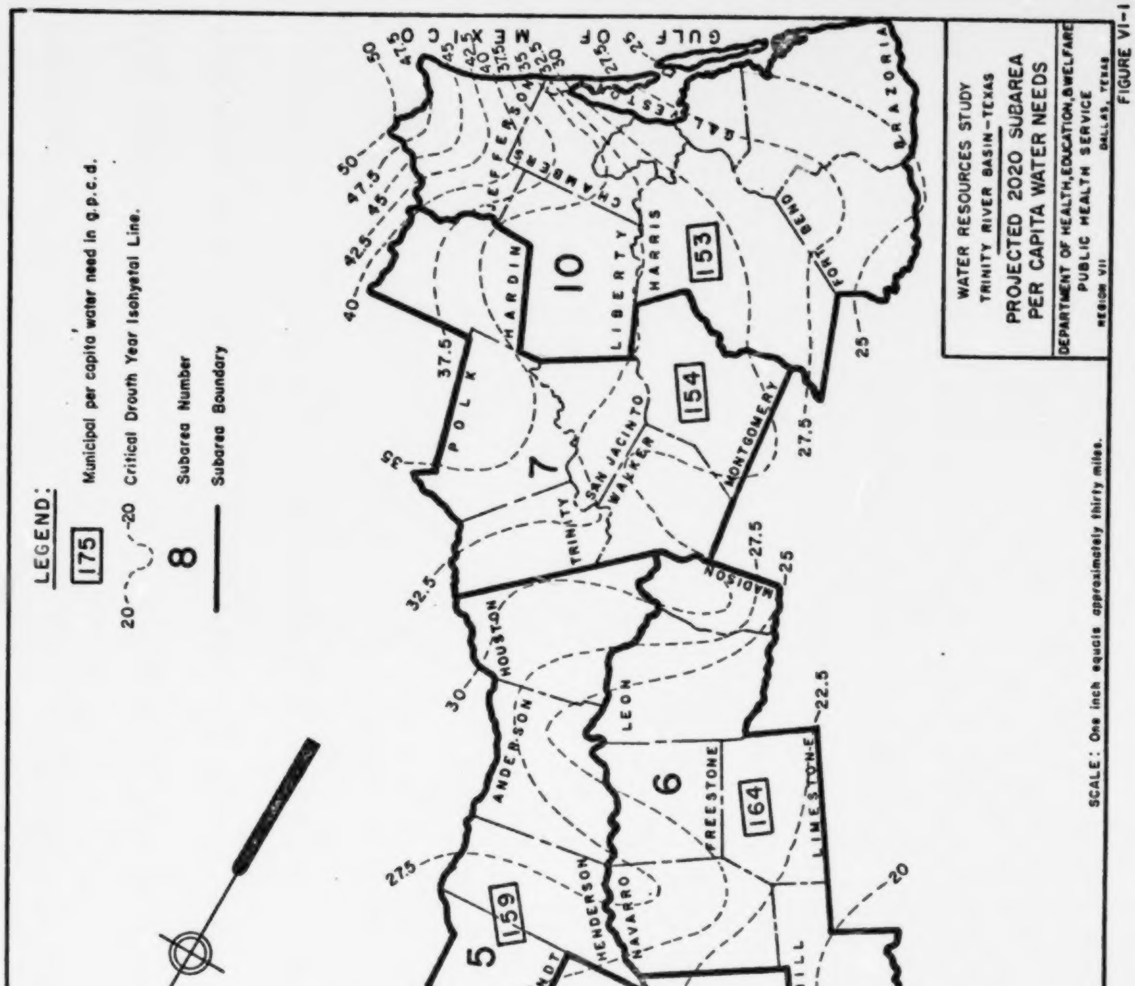
Projected 2020 Subarea Requirements

The projection of municipal needs was accomplished by combining the projected municipal unit water use and the projected municipal population and is fully described in Appendix A. Figure VI-1 shows the projected subarea municipal per capita requirements along with critical drouth year (1956) isohyetal lines. The needs shown are weighted averages of county values. The map illustrates that some weight was placed on the effect of rainfall variation in determining the 2020 county per capita use projections shown in Table A-1, Appendix A.

The method of projecting industrial requirements is also fully described in Appendix A. In this case, the difference in unit employee water use between counties for a given industrial category is easily explained. Base year and projected employment figures show total rather than production employment, and it is assumed that the ratio of production to total employees within an area will not be materially affected by time. Therefore, a county displaying a low unit use for a large water-using industry in the base year would continue to have a relatively low unit use in the future, indicating a low ratio of production to total employees. Conversely, a high unit use in a county would indicate a high ratio of production to total employees. Figure VI-2 shows the projected aggregate industrial unit uses by subarea. Also included are base year figures showing gallons of water used per dollar of value added by manufacture. The latter figures are indicators of the types of industry ("wet" or "dry") present in the base year and serve to corroborate the projected industrial unit use values.

The projections of consumptive use of water by electric utilities in conjunction with thermal power generation as described in Appendix A yield a requirement for this type of water in each county. As such, however, these needs are of no value since it is not realistic to assume that each county will contain a power station capable of supplying its own demand. Indeed, this was not true in the base year or, for that matter, at any time in the history of the electric industry.

At present, the electric power companies maintain a vast interconnected network of transmission lines which can be expected to grow and increase in complexity in the future. From reports of the power companies in the area, it is possible to generally locate some of the larger installations that can be expected in the future. Figure VI-3 was compiled from these data and shows approximately the location of large power generating installations and their expected

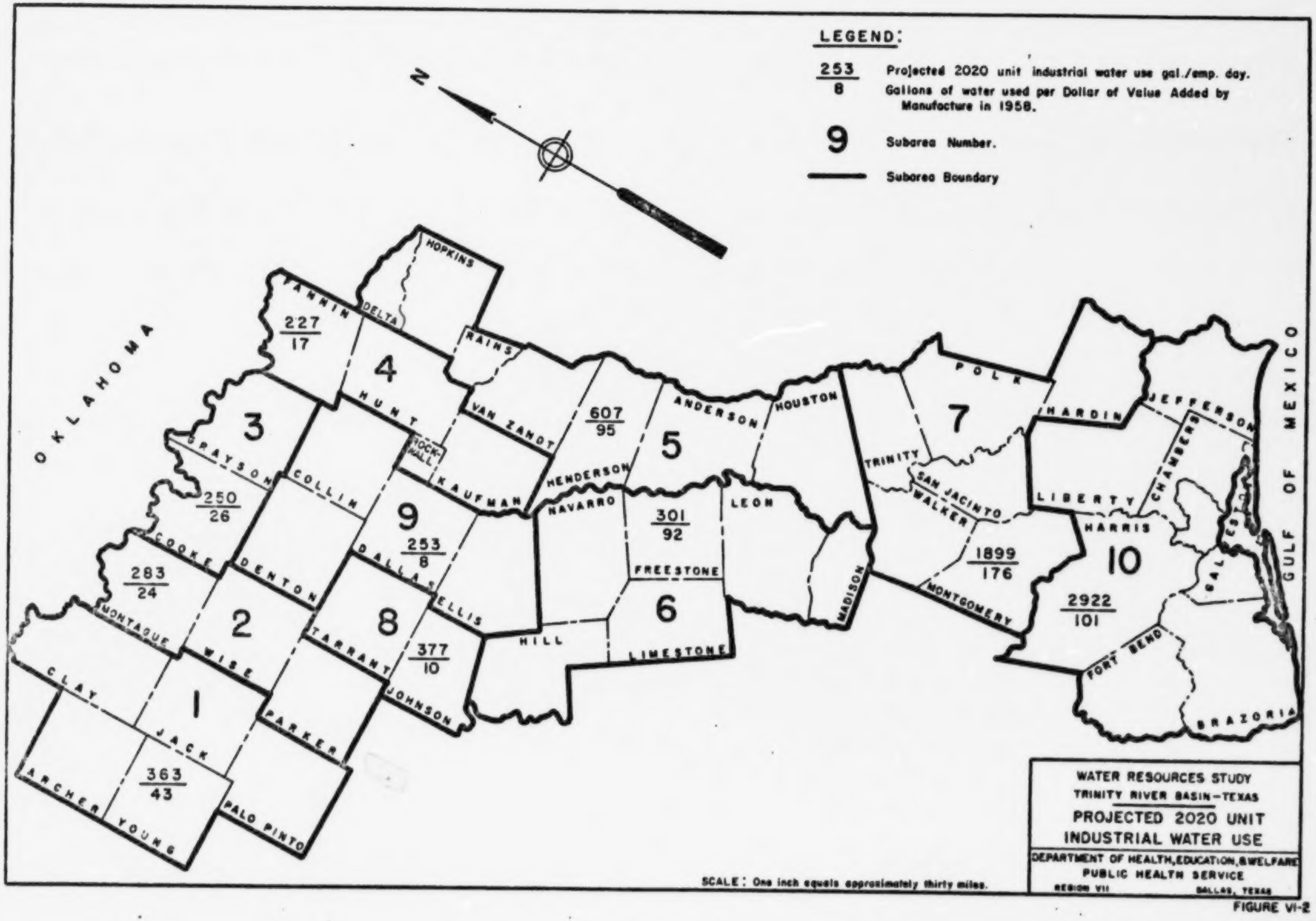


WATER RESOURCES STUDY
TRINITY RIVER BASIN–TEXAS
PROJECTED 2020 SUBAREA
PER CAPITA WATER NEEDS

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

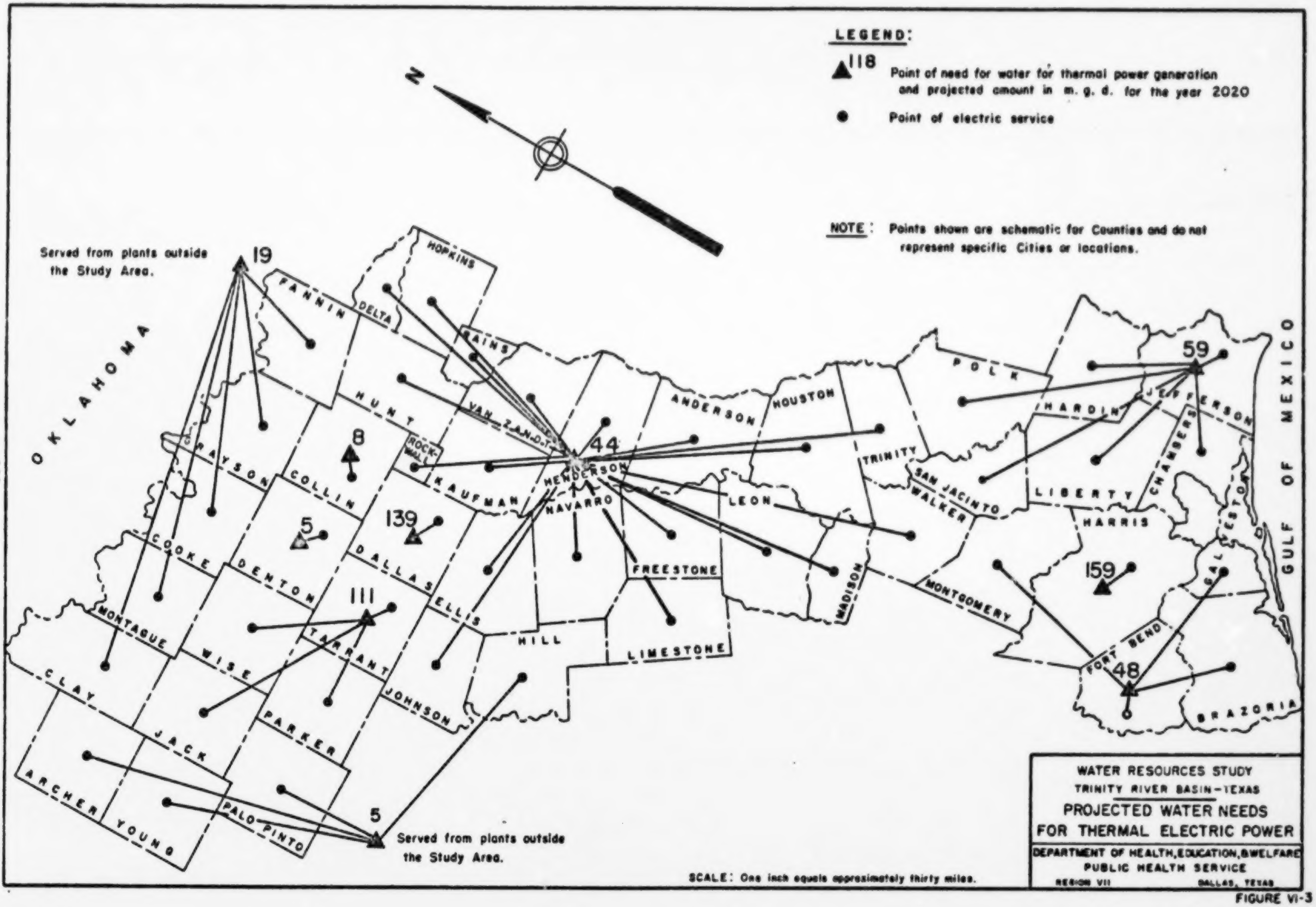
FIGURE VI-1

LEGEND:
175 Municipal per capita water need in g.p.c.d.
20 - - 20 Critical Drouth Year Isohyetal Line.
8 Subarea Number
Subarea Boundary
N
OKLAHOMA
GULF OF MEXICO
SCALE: One inch equals approximately thirty miles.
1
178
2
173
3
170
4
159
5
159
6
164
7
8
175
9
175
10
153
154
ARCHER
YOUNG
CLAY
JACK
MONTAGUE
WISE
PALO PINTO
PARKER
COOKE
DENTON
TARRANT
JOHNSON
GRAYSON
COLLIN
DALLAS
ELLIS
FANNIN
DELTA
HUNT
ROCKWALL
KAUFMAN
HOPKINS
RAINS
VAN ZANDT
HENDERSON
NAVARRO
HILL
FREESTONE
LIMESTONE
ANDERSON
HOUSTON
LEON
MADISON
TRINITY
WALKER
SAN JACINTO
MONTGOMERY
POLK
LIBERTY
HARDIN
HARRIS
CHAMBERS
JEFFERSON
GALVESTON
FORT BEND
BRAZORIA
15
17.5
20
22.5
25
27.5
30
32.5
35
37.5
40
42.5
45
47.5
50


LEGEND:
253/8 Projected 2020 unit industrial water use gal./emp. day. Gallons of water used per Dollar of Value Added by Manufacture in 1958.
9 Subarea Number.
Subarea Boundary
N
OKLAHOMA
GULF OF MEXICO
1
363/43
CLAY
JACK
ARCHER
YOUNG
PALO PINTO
2
283/24
MONTAGUE
WISE
COOKE
DENTON
PARKER
3
250/26
GRAYSON
COLLIN
227/17
FANNIN
4
HUNT
DELTA
HOPKINS
RAINS
ROCKWALL
5
607/95
VAN ZANDT
HENDERSON
ANDERSON
HOUSTON
6
301/92
NAVARRO
FREESTONE
LIMESTONE
HILL
LEON
MADISON
7
TRINITY
POLK
SAN JACINTO
WALKER
1899/176
MONTGOMERY
8
TARRANT
377/10
JOHNSON
ELLIS
9
253/8
DALLAS
KAUFMAN
10
2922/101
HARDIN
JEFFERSON
LIBERTY
CHAMBERS
HARRIS
GALVESTON
FORT BEND
BRAZORIA
SCALE: One inch equals approximately thirty miles.

WATER RESOURCES STUDY
TRINITY RIVER BASIN–TEXAS
PROJECTED 2020 UNIT
INDUSTRIAL WATER USE
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE VI-2


LEGEND:
118 Point of need for water for thermal power generation and projected amount in m. g. d. for the year 2020
Point of electric service
NOTE: Points shown are schematic for Counties and do not represent specific Cities or locations.
N
Served from plants outside the Study Area.
19
OKLAHOMA
FANNIN
DELTA
HOPKINS
RAINS
HUNT
VAN ZANDT
ROCK-WALL
GRAYSON
COLLIN
8
5
139
KAUFMAN
44
HENDERSON
NAVARRO
ANDERSON
HOUSTON
TRINITY
POLK
HARDIN
59
JEFFERSON
CHAMBERS
LIBERTY
SAN JACINTO
WALKER
LEON
HARRIS
159
GALVESTON
GULF OF MEXICO
COOKE
DENTON
DALLAS
ELLIS
111
TARRANT
FREESTONE
MADISON
MONTGOMERY
FORT BEND
48
BRAZORIA
MONTAGUE
WISE
HILL
LIMESTONE
JOHNSON
CLAY
JACK
PARKER
ARCHER
YOUNG
PALO PINTO
5
Served from plants outside the Study Area.
SCALE: One inch equals approximately thirty miles.

WATER RESOURCES STUDY
TRINITY RIVER BASIN-TEXAS
PROJECTED WATER NEEDS
FOR THERMAL ELECTRIC POWER
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE VI-3

service areas. The individual county requirements were accordingly placed at the point that would most likely provide electric service to the county.

The network shown is greatly simplified and serves only to show where the projected needs for this water are placed in the overall plan. Power supplied from within the study area is expected to be entirely supplied by thermal generation methods. For those counties supplied from outside the study area, no attempt was made to determine what portion of the power requirements might be supplied from hydroelectric sources; therefore, the actual water need may be somewhat below that shown in Figure VI-3.

A small segment of the total water requirement which in most reports is largely overlooked is that of the nonmunicipal water supply for purposes other than irrigation. In an area where a terminal year need for all of the water available is anticipated, however, an estimate of these requirements becomes necessary so as not to understate the total water needs.

For purposes of this study, the nonmunicipal requirement is assumed to consist of domestic water for the nonmunicipal population and water for the maintenance of livestock.

The following unit use figures were used for the projections. 7/

Item	Gallons Per Day
Nonmunicipal Population	100
Dairy Cow (including washing)	35
Beef Cattle and Horses	12
Hogs	4
Sheep	2
Fowl	0.07

The present nonmunicipal population 8/ and the number of livestock 20/ were determined. The number of livestock in the year 2020 were extrapolated from 2010 projections made by the U. S. Department of Agriculture. 10/ These values were then combined with the nonmunicipal population projections made for this study and the unit water use values above and translated into average daily nonmunicipal water requirements for each county and subarea.

To complete the water picture, projected irrigation and navigation requirements were obtained through the Corps of Engineers.

Table VI-2 shows 2020 water requirement by subarea for each of the five uses described above along with the subarea and study area totals.

Table VI-2

Projected 2020 Subarea Water Requirements

Sub-area	Total Water	Total* M. & I.	Munic-ipal	Indus-trial	Thermal Power Genera-tion	Non-munic-ipal	Irriga-tion	Naviga-tion
	Water Requirements in MGD							
1	20.9	18.6	15.7	2.9	--	2.3	--	--
2	30.6	27.5	22.7	4.8	--	3.0	0.1	--
3	60.3	55.9	49.2	6.7	--	4.4	--	--
4	80.0	48.5	44.2	4.3	--	4.6	26.9	--
5	196.2	140.2	28.6	67.9	43.7	7.2	48.8	--
6	131.6	77.5	26.8	50.7	--	7.2	46.9	--
7	302.5	268.2	43.6	224.6	--	8.6	25.7	--
8	582.1	580.8	394.9	74.5	111.4	1.1	0.2	--
9	782.7	774.2	554.9	67.5	151.8	3.1	5.4	--
10	3,451.1	3,107.5	793.9	2,047.7	265.9	11.5	275.1	57.0
Study Area	5,638.0	5,098.9	1,974.5	2,551.6	572.8	53.0	429.1	57.0
% of Total	100.0	90.5	35.0	45.3	10.2	0.9	7.6	1.0

* Including consumptive use for thermal power generation.

For the study area, the 2020 over-all municipal and industrial unit use is 423 gpcd. This, compared with a base year value of 293 gpcd, gives an increase of 2.1 gpcd/yr which is somewhat higher than past records for this type of increase as shown in Appendix A. This is due to the large industrial expansion projected for the middle and lower portions of the Trinity basin.

Percentagewise, the municipal and industrial components of the total water requirements are by far the largest with only 9.6 percent of the need being outside this category. Excluding the navigation requirement and putting the remaining 8.5 percent on a unit use basis shows that the nonmunicipal population will use 1,639 gpcd for domestic, livestock, and irrigation purposes.

Projected 2070 Subarea Requirements

In projecting water needs for the year 2070, a very generalized approach, based on the following assumptions, was used.

1. The unit municipal and industrial water use and the unit nonmunicipal water use projected for the year 2020 will prevail for the period 2020 to 2070.

2. The irrigation and navigation water use projections will also remain constant from 2020 to 2070.

Using the above assumptions and the population projections of the Corps of Engineers the subarea water requirements shown in Table VI-3 were determined.

Table VI-3

Projected 2070 Subarea Water Requirements

	Water Requirements in MGD				
Subarea	Total Water	Total* M. & I.	Non-municipal	Irrigation	Navigation
1	33.8	31.9	1.9	--	--
2	58.8	56.5	2.2	0.1	--
3	121.3	119.6	1.7	--	--
4	127.1	95.6	4.6	26.9	--
5	293.4	238.5	6.1	48.8	--
6	191.1	137.0	7.2	46.9	--
7	582.7	549.3	7.7	25.7	--
8	1,091.8	1,091.0	0.6	0.2	--
9	1,429.4	1,421.8	2.2	5.4	--
10	6,249.3	5,909.3	7.9	275.1	57.0
Study Area	10,178.7	9,650.5	42.1	429.1	57.0
% of Total	100.0	94.8	0.4	4.2	0.6

* Including consumptive use for thermal power generation.

For purposes of comparison with previous and concurrent studies and to avoid duplication of water needs in adjoining river basins, projections of water requirement for the area totally within the boundaries of the Trinity River basin were also estimated and are shown in Table VI-4. These were calculated from the subarea projections shown above. In this case, the basin is divided into three parts as follows:

1. Upper: All of the watershed area upstream of the south boundaries of Anderson and Freestone Counties.

2. Middle: The watershed area downstream of the upper basin and upstream of the north boundary lines of Polk and San Jacinto Counties.

3. Lower: The remainder of the watershed area.

Table VI-4

Projected Water Requirements for the Trinity River Basin

	Water Requirements in MGD						
Subbasin	Total	Total M&I*	Non-munic-ipal	Irriga-tion	Naviga-tion	Export	Quality
			For the Year 2020				
Upper	1,677	1,513	15	69	0	0	80
Middle	295	227	3	65	0	0	0
Lower	1,461	340	2	222	57	840	0
Total	3,433	2,080	20	356	57	840	80
			For the Year 2070				
Upper	2,877	2,797	11	69	0	0	0
Middle	504	435	4	65	0	0	0
Lower	1,806	686	1	222	57	840	0
Total	5,187	3,918	16	356	57	840	0

* Including consumptive use for thermal power generation.

VII. PLANS FOR SUPPLYING FUTURE WATER REQUIREMENTS

General

The estimated 2020 municipal and industrial water requirement in the study area, as discussed in the preceding section, is 5,099 mgd. Of this total, it is expected that 1,370 mgd will be supplied from ground water and the remaining 3,729 mgd from surface sources. In addition, the projected nonmunicipal need of 53 mgd is expected to be satisfied wholly from ground water; and, of the projected irrigation requirement of 429.1 mgd, 69.7 mgd, 13.4 mgd, and 346.0 mgd are expected to be satisfied from ground water, in-basin reservoirs and municipal and industrial return flows, respectively. Of the municipal and industrial requirement, 1,281 mgd will come from surface sources other than the Trinity River basin; and, out of this total, 172 mgd will be transferred into the Trinity River basin from Iron Bridge Reservoir in the Sabine River basin. On the other hand, the city of Houston will require 497 mgd out of Livingston-Wallisville Reservoir system in the Trinity River basin. A similar breakdown of supply sources for the year 2070 is shown in Table VII-1.

Table VII-1

Summary of Supply Sources - 2070

Source	Amount (mgd)
Ground water for municipal and industrial use	1,732
Ground water for nonmunicipal use	42
Surface water for municipal and industrial use	7,918
From: Trinity River basin	3,073*
Import to Trinity River basin	180
Export from Trinity River basin to Houston subarea	840*
Reuse of return flows	900
Use of brackish water	2,435
Other river basins	1,330

* 840 mgd is included in the Trinity River basin figure of 3,073.

Plans for the Several Subareas

The plan for supplying the municipal and industrial water requirements of the 10 subareas in the years 2020 and 2070 are shown in Tables VII-2 and VII-3, respectively. In the case of areas outside the Trinity basin, the plan shows only the river basin from which the surface supply to meet the need is expected to come.

Exceptions to this are the Houston Standard Metropolitan Statistical Area and Subareas 4 and 5 where specific supplies other than from the Trinity River basin are shown. Also shown are the estimated return flows and their disposition.

A summary water balance for the Trinity River basin is shown in Table VII-4. This table includes all water resources and requirements.

Table VII-2

2020 Water Supply Plan Summary

(All quantities in mgd)

Sub-area	Total M & I Require-ment	Estimated Ground Water Use	Surface Supply Require-ment	Source of Surface Supply: Source	Source of Surface Supply: Amount	Estimated Return Flow	Disposition of Return Flow: Disposal Stream	Disposition of Return Flow: Gaining Reservoir	Disposition of Return Flow: Amount Returned
1	18.6	0.2	18.4	Bridgeport Res.	1.6	11.2	W. Fk. Trinity	Bridgeport	0.9
				Red River Basin	3.0		Red River	--	1.6
				Brazos R. Basin	13.8		Brazos River	--	8.7
2	27.6	14.0	13.6	Bridgeport Res.	1.2	16.7	Denton Cr.	Roanoke	2.1
				Weatherford Res.	0.6		W. Fk. Trinity	Boyd	0.9
				Boyd Res.	11.8		W. Fk. Trinity	Eagle Mountain	2.1
							Cl. Fk.Trinity	Benbrook	10.2
							Red River	--	1.2
							Elm Creek	Aubrey	0.2
3	55.9	18.8	37.1	Red River Basin	37.1	29.4	Elm Creek	Aubrey	7.0
							Jordan Cr.	Aubrey	0.2
							E. Fk. Trinity	Lavon	0.6
							Red River	--	21.6
4	48.5	0.3	48.2	Lavon Res.	3.7	23.6	Indian Cr.	Lavon	0.1
				Forney Res.	0.1		E. Fk. Trinity	Forney	0.9
				Terrell Res.	0.6		Kings Fork	Cedar Cr.	6.2
				Cedar Creek Res.	0.6		Lacy Fork	Cedar Cr.	0.3
				Iron Bridge (Sabine)	31.8		Buffalo	Tenn. Col.	0.6
				Cooper (Sulphur)	5.9		Bear Cr.	Lavon	0.2
				Red River Basin	5.5		Red River	--	2.1
							Sabine River	--	9.9
							Sulphur River	--	3.3

Table VII-2 (Continued)

2020 Water Supply Plan Summary
(All quantities in mgd)

Sub-area	Total M & I Requirement	Estimated Ground Water Use	Surface Supply Requirement	Source of Surface Supply		Estimated Return Flow	Disposition of Return Flow		
				Source	Amount		Disposal Stream	Gaining Reservoir	Amount Returned
5	140.3	53.2	87.1	Tenn. Col. Res.	43.7	53.7	Ferris Fork	Cedar Cr.	0.8
				Gail Res.	19.9		Cedar Cr.	Tenn. Col.	5.7
				Hurricane Res.	17.5		Box Cr.	Livingston	0.3
				Cooper (Sulphur)	6.0		Elkhart Cr.	Livingston	2.8
							Tantabogue	Livingston	1.4
							Sulphur River	--	0.6
							Sabine River	--	4.5
							Neches River	--	15.3
							Gail Cr.	Gail	22.3
6	77.5	52.3	25.2	Navarro Mills	11.6	42.8	Richland Cr.	Navarro Mills	0.4
				Richland Cr.	0.4		Richland Cr.	Navarro Mills	
				Bedias Res.	12.0		Pinoak Cr.	Navarro Mills	
				Brazos R. Basin	1.2		Ash Creek	Navarro Mills	
							Richland Cr.	Richland	0.3
							Pinoak Cr.	Richland	0.2
							Chambers Cr.	Richland	5.3
							Rush Cr.	Tenn. Col.	0.1
							Plumber Cr.	Tehuacana	1.3
							Tehuacana Cr.	Tehuacana	1.0
							Cottonwood Cr.	Tehuacana	2.9
							Caney Cr.	Tehuacana	2.5
							U. Keechi Cr.	Upper Keechi	5.7
							U. Keechi Cr.	Upper Keechi	2.8
							L. Keechi Cr.	Lower Keechi	4.5
							Caney Cr.	Bedias	11.8
							Brazos R. Basin	--	4.0

Table VII-2 (Continued)

2020 Water Supply Plan Summary
(All quantities in mgd)

Sub-areas	Total M & I Require-ment	Estimated Ground Water Use	Surface Supply Require-ment	Source of Surface Supply		Estimated Return Flow	Disposition of Return Flow		
				Source	Amount		Disposal Stream	Gaining Reservoir	Amount Returned
7	268.1	125.7	142.4	Caney Res.	25.2	175.2	Kickapoo Cr.	Livingston	9.9
				Gail Res.	8.7		Trinity River	Livingston	11.9
				Harmons Res.	88.0		Harmons Cr.	Livingston	71.2
				Bedias Res.	20.5		Long Tom Cr.	Wallisville	28.7
							Trinity River	Wallisville	6.6
							San Jacinto R.	--	31.3
							Neches River	--	15.6
8	580.8	77.8	503.0	Bridgeport Res.	48.5	295.8	Trinity River	Tenn. Col.	190.1
				Boyd Res.	20.8		Mountain Cr.	Lakeview	9.3
				Eagle Mountain - Lakeworth	19.5		Village Cr.	Arlington	2.5
				Arlington Res.	8.3		Chambers Cr.	Richland	1.8
				Cedar Cr. Res.	179.9		Brazos River	--	6.8
				Richland Res.	76.0		Consumptive Re-use		85.4
				Tehuacana Res.	64.6				
				Return Flows for Cooling	85.4				

Table VII-2 (Continued)

2020 Water Supply Plan Summary
(All quantities in mgd)

Sub-area	Total M & I Require-ment	Estimated Ground Water Use	Surface Supply Require-ment	Source of Surface Supply: Source	Source of Surface Supply: Amount	Estimated Return Flow	Disposition of Return Flow: Disposal Stream	Disposition of Return Flow: Gaining Reservoir	Disposition of Return Flow: Amount Returned
9	774.2	52.6	721.6	Garza-Little Elm	85.4	303.7	White Rock Cr.	White Rock	7.3
				Lavon Res.	84.1		Elm Creek	Garza-Little Elm	9.1
				Grapevine	44.4		Elm Creek	Tenn. Col.	1.8
				Forney	64.6		Elm Creek	Aubrey	0.1
				Lakeview	40.0		Denton Cr.	Roanoke	0.2
				Tenn. Col.	43.6		E. Fk. Trinity	Lavon	8.7
				Aubrey	82.5		E. Fk. Trinity	Forney	5.0
				Bardwell	5.1		Trinity River	Tenn. Col.	0.2
				Waxahachie	1.9		Red Oak Cr.	Tenn. Col.	0.1
				Return Flows for Cooling	110.2		W. Fk. Trinity	Tenn. Col.	134.1
				Iron Bridge (Sabine)	159.8		E. Fk. Trinity	Tenn. Col.	20.7
							Chambers Cr.	Richland	1.8
							Mountain Cr.	Lakeview	0.3
							Waxahachie Cr.	Bardwell	3.0
							Denton Cr.	Grapevine	0.1
							Sabine R.	--	0.3
							Consumptive Re-use		110.2
10	3,107.5	975.2	2,132.3	Livingston - Wallisville System	1,114.8	1,771.5	Trinity River	Wallisville	171.2
				San Jacinto Basin			San Jacinto and Coastal Basins		855.8
				Humble	164.5		Brazos and Coastal Basins		189.7
				Hones	111.0		Coastal Basins		554.8
				Dobbin	25.5				
				Cleveland	99.0				
				Houston	28.5				
				Neches R. Basin	429.0				
				Brazos R. Basin	160.0				

Table VII-3

2070 Water Supply Plan Summary
(All quantities in mgd)

Sub-area	Total M & I Requirement	Estimated Ground Water Use	Surface Supply Requirement	Source of Surface Supply: Source	Source of Surface Supply: Amount	Estimated Return Flow	Disposition of Return Flow: Disposal Stream	Disposition of Return Flow: Gaining Reservoir	Disposition of Return Flow: Amount Returned
1	31.9	0.2	31.7	Bridgeport Res.	2.1	15.9	W. Fk. Trinity	Bridgeport	0.9
				Red River Basin	4.5		Red River	--	2.2
				Brazos River Basin	25.1		Brazos River	--	12.8
2	56.5	52.9	13.6	Bridgeport Res.	1.2	28.3	Denton Cr.	Roanoke	4.1
				Weatherford Res.	0.6		Elm Creek	Aubrey	2.4
				Boyd Res.	11.8		W. Fk.Trinity	Boyd	1.4
							W. Fk.Trinity	Eagle Mountain	3.5
							Cl. Fk.Trinity	Benbrook	16.6
							Red River	--	0.3
3	119.6	42.6	77.0	Red River Basin	77.0	59.7	Elm Creek	Aubrey	14.2
							Jordan Cr.	Aubrey	0.3
							E. Fk. Trinity	Lavon	1.3
							Red River	--	43.9
4	95.6	4.8	90.8	Lavon Res.	7.2	47.8	Indian Cr.	Lavon	0.3
				Forney Res.	4.7		Bear Cr.	Lavon	0.4
				Terrell Res.	0.6		E. Fk. Trinity	Forney	1.9
				Cedar Cr. Res.	1.2		King Fork	Cedar Cr.	12.6
				Iron Bridge (Sabine)	40.0		Lacy Fork	Cedar Cr.	0.5
				Cooper (Sulphur)	29.3		Buffalo	Tenn. Col.	1.1
				Red River Basin	7.8		Red River	--	4.5
							Sulphur River	--	6.6
							Sabine River	--	19.9

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Table VII-3 (Continued)

2070 Water Supply Plan Summary
(All quantities in mgd)

Sub-area	Total M & I Require-ment	Estimated Ground Water Use	Surface Supply Require-ment	Source of Surface Supply		Estimated Return Flow	Disposition of Return Flow		
				Source	Amount		Disposal Stream	Gaining Reservoir	Amount Returned
5	238.4	96.7	141.7	Tenn. Col. Res.	69.6	84.0	Ferris Fork	Cedar Creek	1.6
				Hurricane Res.	17.5		Cedar Creek	Tenn. Col.	9.1
				Gail Res.	43.6		Box Cr.	Livingston	0.7
				Cooper Res.	11.0		Elkhart Cr.	Livingston	3.9
							Gail Cr.	Gail	30.8
							Tantabogue	Livingston	1.9
							Neches R.	--	27.1
							Sabine R.	--	7.9
							Sulphur R.	--	1.0
6	136.9	94.2	42.7	Navarro Mills	18.6	68.5	Richland Cr.	Navarro Mills	(0.7
				Richland Res.	0.6		Richland Cr.	Navarro Mills	(
				Bedias Res.	21.3		Pinoak Cr.	Navarro Mills	(
				Brazos River Basin	2.2		Ash Creek	Navarro Mills	(
							Richland Cr.	Richland	0.5
							Chambers Cr.	Richland	8.9
							Pinoak Creek	Richland	0.2
							Rush Cr.	Tenn. Col.	0.2
							Plumber Cr.	Tehuacana	2.0
							Tehuacana Cr.	Tehuacana	1.6
							Cottonwood Cr.	Tehuacana	5.0
							Caney Cr.	Tehuacana	4.3
							U. Keechi Cr.	Upper Keechi	8.6
							U. Keechi Cr.	Upper Keechi	4.2
							L. Keechi Cr.	Lower Keechi	6.9
							Caney Cr.	Bedias	19.4
							Brazos River	--	6.0

Table VII-3 (Continued)

2070 Water Supply Plan Summary
(All quantities in mgd)

Sub-area	Total M & I Require-ment	Estimated Ground Water Use	Surface Supply Require-ment	Source of Surface Supply		Estimated Return Flow	Disposition of Return Flow		
				Source	Amount		Disposal Stream	Gaining Reservoir	Amount Returned
7	549.3	263.6	285.7	Mustang Res.	25.2	274.7	Kickapoo Cr.	Livingston	16.0
				Caney Res.	25.2		Trinity River	Livingston	19.3
				Gail Res.	18.2		Harmons Cr.	Livingston	110.6
				Harmons Res.	16.8		Long Tom Cr.	Wallisville	45.5
				Bedias Res.	92.5		Trinity River	Wallisville	12.3
				Upper Keechi Res.	67.1		San Jacinto R.	--	46.0
				Lower Keechi Res.	32.1		Neches R.		25.0
				Livingston	8.6				
8	1,091.0	79.1	1,011.9	Tenn. Col. Res.	115.0	545.5	W. Fk.Trinity	Tenn. Col.	511.3
				Bridgeport Res.	48.0		Mountain Creek	Lakeview	16.8
				Boyd Res.	21.3		Village Cr.	Arlington	4.0
				Eagle Mountain -			Chambers Cr.	Richland	2.7
				Lake Worth	20.9		Brazos R.	--	10.6
				Arlington Res.	9.8				
				Cedar Cr. Res.	186.7				
				Richland Res.	184.8				
				Tehuacana Res.	69.8				
				Recirculated Return Flow	355.6				

Table VII-3 (Continued)

2070 Water Supply Plan Summary
(All quantities in mgd)

Sub-area	Total M & I Require-ment	Estimated Ground Water Use	Surface Supply Require-ment	Source of Surface Supply		Estimated Return Flow	Disposition of Return Flow		
				Source	Amount		Disposal Stream	Gaining Reservoir	Amount Returned
9	1,421.8	81.5	1,340.3	Garza-Little Elm	99.4	710.8	White Rock Cr.	White Rock	11.1
				Lavon	94.5		Elm Creek	Garza-Little Elm	23.1
				Bardwell	10.4		Elm Creek	Tenn. Col.	4.5
				Waxahachie	1.9		Elm Creek	Aubrey	0.5
				Aubrey	92.4		Denton Cr.	Roanoke	0.3
				Grapevine	46.7		Denton Cr.	Grapevine	0.3
				Forney	68.3		E. Fk.Trinity	Lavon	21.5
				Lakeview	47.8		E. Fk.Trinity	Forney	12.3
				Tenn. Col.	175.8		W. Fk.Trinity	Tenn. Col.	572.1
				Iron Bridge (Sabine)	159.8		E. Fk.Trinity	Tenn. Col.	53.4
				Recirculated Return Flows	543.3		Trinity River	Tenn. Col.	0.5
							Red Oak Cr.	Tenn. Col.	0.1
							Chambers Cr.	Richland	3.6
							Mountain Creek	Lakeview	0.6
							Waxahachie Cr.	Bardwell	6.2
							Sabine R.	--	0.7
10	5,909.3	1,026.7	4,882.6	Capers Ridge	97.0	2,755.6	San Jacinto Basin	--	1,335.6
				Livingston - Wallisville System	1,216.8		Coastal Basins	--	861.7
				San Jacinto Basin			Brazos Basin	--	337.4
				Humble	164.5		Trinity River	Wallisville	220.9
				Honea	111.0				
				Dobbin	25.5				
				Cleveland	99.0				
				Houston	28.5				
				Neches R. Basin	338.7				
				Brazos R. Basin	366.3				
				Brackish Water for Cooling	2,435.3*				

* Used in Neches, San Jacinto, and Brazos River basin portions of Subarea 10.

Table VII-4

2020 and 2070 Water Balance
(All quantities in mgd)

	Resources					Requirements							
Subbasin	Reservoir Yields	Imports	Ground Water	Reused Water	Total	Munic. & Indus.	Non-municipal	Water Quality Control	Navigation	Irrigation	Exports	Total
					For the Year 2020							
Upper	1,190	172	220	364	1,946	1,513	15	80	0	69	0	1,677
Middle	290	0	41	30	361	227	3	0	0	65	0	295
Lower	719	0	280	604	1,603	340	2	0	57	222	840	1,461
Total	2,199	172	541	998	3,910	2,080	20	80*	57	356	840	3,433
					Surplus:	477 mgd						
					For the Year 2070							
Upper	1,190	180	338	1,340	3,048	2,797	11	0	0	69	0	2,877
Middle	290	0	75	160	525	435	4	0	0	65	0	504
Lower	817	0	333	701	1,851	686	1	0	57	222	840	1,806
Total	2,297	180	746	2,201	5,424	3,918	16	0	57	356	840	5,187
					Surplus:	237 mgd						

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* This requirement is determined in Section VIII, which follows.

The plans shown in the preceding tables were chosen because they provide for an orderly development of the basin's water resources and at the same time recognize local and state permits and agreements.

Sequence of Construction

In order to efficiently implement the water supply plan above, a sequence of reservoir construction based on the following assumptions was developed.

1. The time of completion for each reservoir is based on need for municipal and industrial and/or quality control even in the case of multiple-purpose projects.
2. The practice of constructing water supply reservoirs 10 years prior to projected need by municipalities in this area will continue.
3. Certain projects are considered existing by the year 1970. These are: Forney Reservoir, Cedar Creek Reservoir, Bardwell Reservoir, Navarro Mills Reservoir, and Livingston Reservoir in the Trinity River basin.
4. The following reservoirs are considered as firmly committed by the year 1970: Lakeview Reservoir, Tennessee Colony Reservoir, enlargement of Lavon Reservoir, and Wallisville Reservoir.
5. The earliest possible date of completion for all remaining reservoir projects is the year 1970.
6. All reservoirs shown in Table IV-3, Appendix E, will be completed by the year 2020.

A plot of municipal and industrial water need and supply versus time for each subarea gave the required time of completion for all reservoirs. In the case of a reservoir whose yield was divided among two or more subareas, the date of completion was determined by the subarea which had the earliest need for the project.

The date (year) of completion for each of the reservoirs as determined from the above analysis is shown in Table VII-5.

Table VII-5

Water Supply Plan - Sequence of Construction

Year	Project Name	Project Type	Remarks
1970	Forney Reservoir	M&I [a]	Under construction
	Cedar Creek Reservoir	M&I	Under construction
	Bardwell Reservoir	MP [b]	Authorized
	Navarro Mills Reservoir	MP	Under construction
	Livingston Reservoir	M&I	Under construction
	Lakeview Reservoir	MP	Firmly committed
	Tennessee Colony Reservoir	MP	Firmly committed
	Lavon Reservoir Enlargement	M&I	Firmly committed
	Wallisville Reservoir	MP	Firmly committed
	Harmons Creek Reservoir	M&I	
	Aubrey Reservoir	MP	Required for quality control
	Hurricane Reservoir	M&I	
1975	Bedias Reservoir	M&I	
1980	Boyd Reservoir	M&I	
1998	Richland Creek Reservoir	M&I	
	Tehuacana Reservoir	M&I	
2000	Roanoke Reservoir	FC [c]	To increase yield of Grapevine
	Caney Creek Reservoir	M&I	
2005	Gail Reservoir	M&I	
2020	Mustang Reservoir	M&I	
	Long King Reservoir	M&I	
	Upper Keechi Reservoir	M&I	
	Lower Keechi Reservoir	M&I	
2060	Capers Ridge Reservoir	M&I	

[a] Municipal and industrial water supply reservoir.

[b] Multiple-purpose reservoir.

[c] Flood control reservoir.

VIII. STREAM QUALITY CONTROL

General

Discharge of wastes, even when treated to the maximum feasible and practical limits possible with known treatment methods, will cause an unsatisfactory quality condition in receiving waters when their assimilation capacity is exceeded. This condition occurs during periods of low streamflows and may be avoided by the addition of water to maintain the stream at a level capable of assimilating the waste. When treatment methods improve, the need for addition of water to maintain quality will diminish and may someday entirely disappear. Until such time, however, it is essential that recognition be given to the need for flows which must prevail in receiving streams if their water quality is to be maintained at acceptable levels. Therefore, estimates of the water required to maintain quality in the Trinity River basin and in the Buffalo Bayou watershed have been made since these needs are an inseparable part of the water supply plan for the study area. For the remainder of the area outside the Trinity River basin, studies of waste disposal were not made since these wastes were not expected to affect the interbasin transfer of water. These estimates are based on certain broad parameters and minimum quality standards fully described in Appendix C.

Provisions of the Federal Water Pollution Control Act, Public Law 84-660, as amended, require that consideration be given to the inclusion of storage for water quality purposes in the survey or planning of all Federal reservoir projects. It is further stipulated that such water storage and its subsequent release shall be provided only after adequate treatment or other source controls of wastes fail to maintain stream quality.

Organic Quality of Trinity River Basin Waters

As previously discussed in Section IV, the present quality of the Trinity River is organically poor in a large part of the upper basin. This is caused by an organic load of about 45,000 pounds of BOD per day, approximately 90 percent of which is exerted by the cities of Dallas and Fort Worth. 13/ Treatment efficiencies vary between 17 percent and 100 percent, with a weighted average of 85 percent removal of BOD. To maintain 4.0 mg/l of dissolved oxygen in the stream between Fort Worth and the Tennessee Colony Reservoir site in the year 1960 would have required an average release of 110 mgd of dilution water.

Dallas and Fort Worth are expected to continue to be the major contributors of pollution loads to the upper Trinity River basin. The projected 2020 BOD load exerted by these cities is about 145,000 pounds per day assuming 90 percent removal. Maintenance of satisfactory stream conditions in the same reach (4.0 mg/l dissolved oxygen) will then require an average annual release of about 300 mgd of dilution water.

Mineral Quality of Trinity River Basin Waters

The mineral quality of the Trinity River basin can be presently described as good to very good except for portions of the coastal region where intrusion of brackish water from the Gulf of Mexico has increased in dissolved solids concentrations to as much as 1,000 mg/l. As development proceeds, however, waste loads will increase; reuse of water will become more prevalent; and increased concentrations of mineral solids can be expected to result. Based on the analysis described in Appendix C, no regulation flow will be needed to correct mineral quality in the year 2020. The waters of the basin, however, will experience a considerable increase in dissolved solids concentrations as shown in Table VIII-1, Appendix E. Concentrations in excess of 500 mg/l will be common throughout the entire area if the critical year of the design drouth period occurs in 2020.

Since this analysis showed that water available for regulation of mineral quality will contain more than 500 mg/l of total dissolved solids, the upper limit for solids was fixed at 1,000 mg/l. Although it is not desirable, this value was chosen because it is still tolerable from a public health standpoint.

Availability of Quality Control Water

An examination of the basin's water resources showed that the waters available for quality control upstream of the points of need are not adequate to raise the dissolved oxygen in the stream to an acceptable level.

Further studies, however, indicated that a plan for maintaining the water quality of the basin could be developed through efficient use of available dilution water and allowances for improved waste treatment technology.

Since this report recognizes prior commitments, agreements, and permits of local interests, storage for water quality control is available only in the several proposed Federal projects, the largest of which is located downstream of the points of need. After 1970, about 65 mgd of water will be available in Aubrey Reservoir above Dallas on an interim basis. This quantity will gradually decrease until it is all needed to meet municipal and industrial requirements.

Basin Operations Plan to Maintain Water Quality

There is no water available for quality control in basin reservoirs upstream of Fort Worth. Therefore, the first stage of development to meet water quality requirements is a pipeline from

Tennessee Colony Reservoir to Benbrook Reservoir by the year 1970 which will transport a yearly average of 80 mgd. This water is to be released from Benbrook Reservoir to satisfy monthly needs varying from 136 mgd in July to 29 mgd in January during the year 1970. Also to be constructed by this time is Aubrey Reservoir. Additional releases from this source amounting to an annual average of 40 mgd in 1970 are required to abate the pollution imposed by the city of Dallas. This first stage development will satisfy water quality needs in the upper basin until the year 1985.

Additional treatment to improve the oxygen economy in the effluents of the Fort Worth, Trinity River Authority, and Dallas waste treatment plants will be required by the year 1985. This additional treatment, coupled with 80 mgd of dilution water from Tennessee Colony Reservoir will be adequate to satisfy water quality needs in the upper Trinity River basin until the year 2020.

After the year 2020, the water from Tennessee Colony Reservoir will be needed to meet municipal and industrial requirements in the upper basin and should revert to this use completely by the year 2040. In all probability, waste treatment technology will have advanced sufficiently to negate the need for quality control water beyond the year 2020. The period of 20 years between 2020 and 2040 allows from stage construction of such facilities. On this premise, no needs for quality control water were projected beyond this year.

In the Houston area, continued disposal of wastes into the Buffalo Bayou watershed and the Houston ship channel, even when treated to remove 90 percent of the organic pollutants, will require average annual regulation flows approximating 1,200 mgd, and a maximum monthly flow in excess of 2,000 mgd in the year 2020. At present, there seems little likelihood that such flows could be made available.

An alternative which would be effective to the terminal year of the study, and probably beyond, would be the construction of one or a series of outfall lines to discharge treated wastes from the Houston complex into the Gulf of Mexico at a suitable point offshore. Further studies of this nature are, however, beyond the scope of this report.

IX. BENEFITS OF STORAGE

Evaluation Method

The report of the Sub-Committee on Evaluation Standards of the Federal Inter-Agency Committee on Water Resources [23] makes the following comment on evaluation of municipal and industrial water supply:

> "From an over-all public viewpoint, a municipal and industrial water supply development will be economically justified if it provides water to meet expected needs at a cost not greater than the cost of the alternative source that would likely be utilized in the absence of the project."

The alternative cost method has been used for evaluation of all storage proposed in this report.

Costs

For purposes of comparison of alternatives, capital costs were converted to equivalent annual costs using an amortization period of 100 years and a non-Federal interest rate of 4 percent. The costs so determined for the date of first use of the project are discounted to their "present" value which in this report refers to the year 1970.

Alternative Plans

Six of the 19 proposed reservoirs in the Trinity River basin are Federal projects. These are Lakeview Reservoir, Tennessee Colony Reservoir, Aubrey Reservoir, Roanoke Reservoir, Wallisville Reservoir, and the enlargement of Lavon Reservoir. Benefits attributable to the latter two projects are covered in earlier Public Health Service reports and are shown in Table IX-1. [24,25]

Table IX-1

Benefits of Storage in Wallisville and Enlarged Lavon Reservoirs

Project	Yield (mgd)	Annual Benefits ($)
Wallisville (Water Supply)	146.0	359,000
Lavon Enlargement (Water Supply)	42.7*	935,100

*Yields shown are increases resulting from reservoir enlargement.

The water supply plan reveals a need for all water that can be economically developed in the Trinity River basin. And investigations of water supply sources in surrounding basins indicate that there are no sources of suitable quality water available, other than those already included in the plan. Therefore, the alternatives to Lakeview, Aubrey, Roanoke, and Tennessee Colony Reservoirs are single-purpose reservoirs at the project sites.

A yield-requirement analysis determined a need for water quality and/or water supply storage in Lakeview, Tennessee Colony, and Aubrey Reservoirs by the year 1970. In addition, the Corps of Engineers has received adequate assurances from the city of Grand Prairie, Texas, [26] and the Trinity River Authority [27] committing the entire conservation yield of the Lakeview and Tennessee Colony Reservoirs and other features of the over-all Trinity River basin development plan at the earliest possible date. Therefore, no discounting of the benefits calculated for these projects is made.

The benefit calculated for Roanoke Reservoir is discounted since the earliest need for storage at this site is the year 2000.

Benefits attributable to these projects are shown in Table IX-2.

Table IX-2

Benefits of Storage in Lakeview, Aubrey, Roanoke, and Tennessee Colony Reservoirs

Project	Yield (mgd)	Annual Benefits ($)
Lakeview (Water Supply Only)	28.4 [a]	907,300
Aubrey (Water Supply and Quality Control)	65.3 [b]	1,085,200
Roanoke (Water Supply Only)	23.9 [b]	210,800 [c]
Tennessee Colony (Water Supply and Quality Control)	290.8	5,589,600 [d]

a/ Yield does not include 2.0 mgd utilized by the existing Mountain Creek Reservoir.

b/ Yields shown are increases in system yields based on storage exchange with Grapevine and Garza-Little Elm Reservoirs.

c/ Discounted 30 years from 2000 to 1970.

d/ Includes 84-inch pipeline and pumping facilities to provide 80 mgd of water for quality control upstream of Fort Worth.

The benefits of storage as shown above for Aubrey and Tennessee Colony Reservoirs must be divided between municipal and industrial and water quality control purposes in accordance with the portion of storage used for each as outlined in the water supply plan and water quality control sections of this report. Since this varies with time, it follows that the part of the total benefit attributable to each purpose also varies. Benefits shown in Table IX-3 were calculated in this way by decades until the total benefit becomes attributable to storage for municipal and industrial water supply purposes.

Table IX-3

Benefits of Storage for Municipal and Industrial Water Supply and Water Quality Control Purposes in Tennessee Colony and Aubrey Reservoirs

	Annual Benefits ($)			
	Tennessee Colony Res. Yield: 290.8 mgd		Aubrey Res. Yield: 65.3 mgd	
Year	M. & I. Water Supply	Water Quality Control	M. & I. Water Supply	Water Quality Control
1970	1,260,400	4,329,200	-0-	1,085,200
1980	1,260,400	4,329,200	65,100	1,020,100
1985			119,400	965,800
1990	1,260,400	4,329,200	1,085,200	-0-
2000	1,260,400	4,329,200		
2010	1,260,400	4,329,200		
2020	1,260,400	4,329,200		
2030	3,657,800	1,931,800		
2040	5,589,600	-0-		

X. APPENDIX

APPENDIX A

WATER USE FACTORS

General

This study was undertaken as a part of the Water Resources Study, Trinity River Basin, Texas, to determine past and present municipal and industrial water use patterns for the study area, thus providing a basis for projecting these quantities to the terminal year of the study.

The approach to projecting water requirements used in the report is presented herein. Municipal water use is expressed in gallons per capita day and industrial water use in gallons per employee day.

For purposes of this study, municipal water use is defined as municipally supplied water for all purposes excluding that supplied by municipalities to industrial establishments. Industrial water, then, is all water regardless of source, used by industrial establishments.

Sources of Data

Data on water use for the study were obtained from the following sources:

1. Inventory of Municipal Water Facilities, U. S. Public Health Service, 1954, 1956, 1957 and 1959.
2. Texas State Department of Health.
3. Texas Water Commission.
4. Bureau of Business Research, University of Texas, Survey of Industrial Water Use, 1958.
5. Regional office field studies.

Supplementary data on climate, population, and personal income were obtained from the U. S. Weather Bureau, Bureau of the Census, and Sales Management magazine, respectively.

Municipal Water Use

Data from the Public Health Service inventories were arrayed by county and a weighted average for each county calculated. Discrepancies in the data were adjusted from additional information obtained from one or several of the other data sources. In this way, county municipal per capita use figures were established.

These data were then correlated with several parameters thought to have an influence on per capita consumption.

During this portion of the study, a departure from the definition of municipal water use as previously defined was made. The per capita use figures here include all municipally supplied treated water regardless of use.

The parameters used, along with a brief discussion of each, were as follows:

1. Size of City. Although the data used in this case were county totals, the size of city is reflected in the population served. Two years of data were used: 1956 being a drouth year and 1957 being a year of excessive precipitation. Municipal populations ranged from several hundred to one million. The two regression lines developed by a least square analysis of the data are shown in Figure A-1. The absence of correlation here illustrates that there is very little increase in per capita consumption with size of city. It should also be noted that the two lines are generally parallel and separated by approximately 20 gpcd, illustrating the increased water demand during a drouth year.

2. Rainfall. This parameter was plotted against per capita consumption for two years (1956 and 1957) as shown in Figure A-2. These two years were again chosen because 1956 was a drouth year and 1957 was a year of excessive precipitation. A regression line was computed for each group of points which indicates that the function of rainfall is possibly discontinuous in the vicinity of 40 inches.

3. Per Capita Income.* The plot in Figure A-3 indicates that there is almost no correlation between per capita income and per capita consumption on a countywide basis. Other studies have shown that income does have an effect on per capita water consumption in relatively homogeneous areas of a specific city; however, on a countywide basis, no effect was evident.

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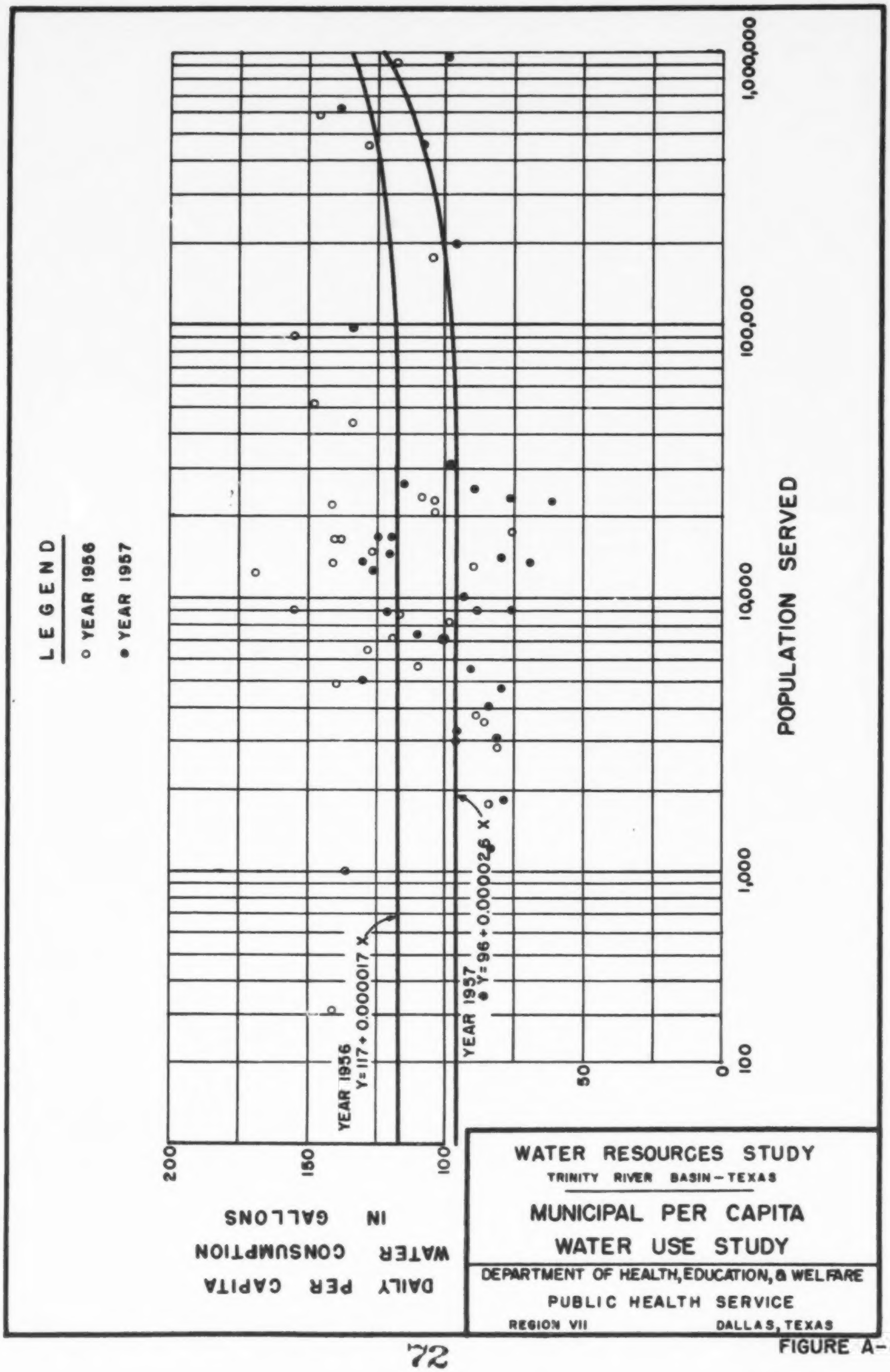
* "Survey of Buying Power," Sales Management Magazine, Vol. 82, No. 10, New York, May 10, 1959.

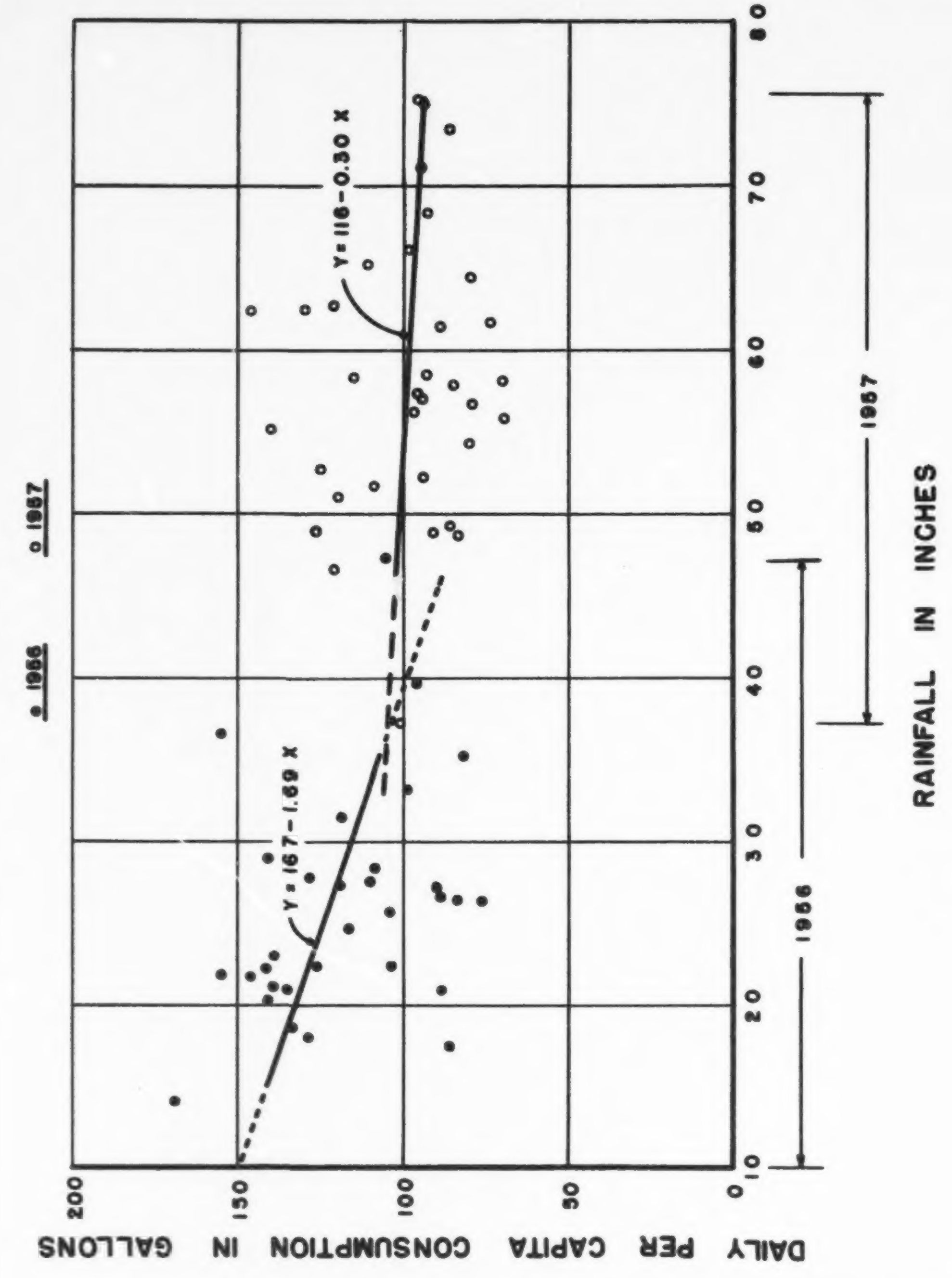


WATER RESOURCES STUDY
TRINITY RIVER BASIN – TEXAS

MUNICIPAL PER CAPITA
WATER USE STUDY

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE A-1

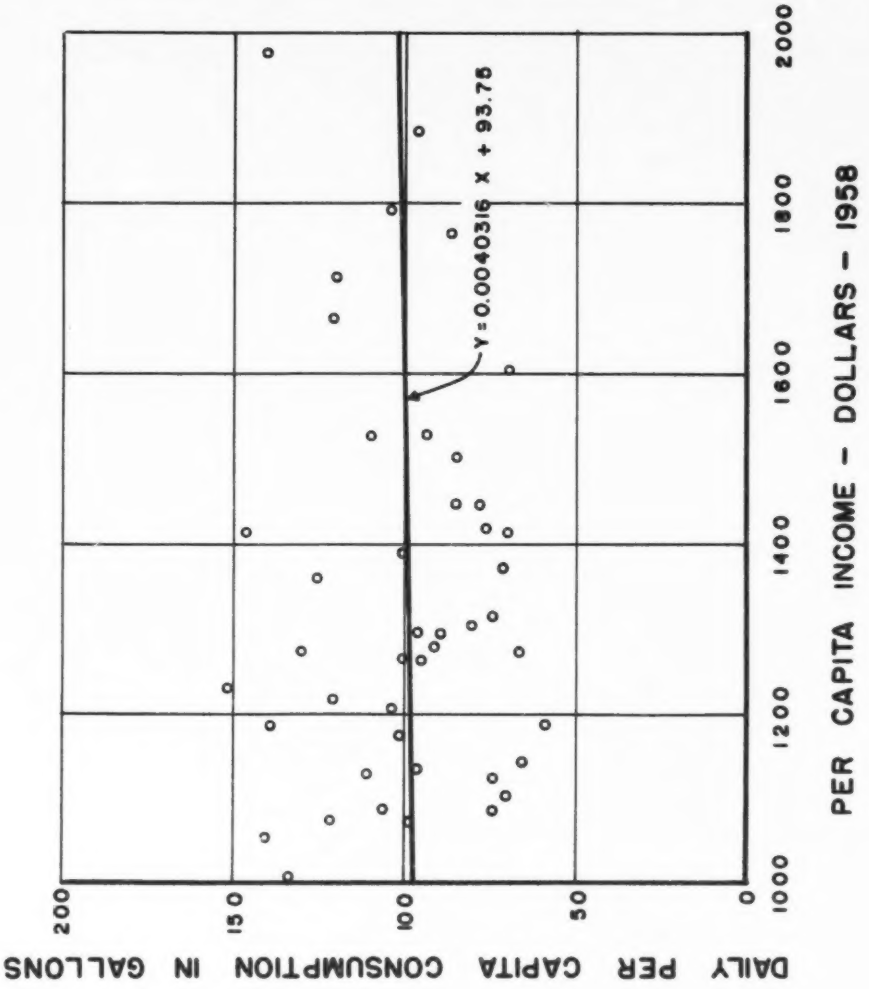


WATER RESOURCES STUDY
TRINITY RIVER BASIN-TEXAS

MUNICIPAL PER CAPITA
WATER USE STUDY

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE A-2



WATER RESOURCES STUDY
TRINITY RIVER BASIN - TEXAS

MUNICIPAL PER CAPITA
WATER USE STUDY

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE A-3

4. Climate Factor. Of the three parameters discussed above, rainfall seemed to be the only one displaying any appreciable effect on per capita consumption. On this basis, it was decided to try to improve this relation by introducing modifying factors which take into account the distribution of rainfall and the threat of rainfall or cloudiness. The latter factor was included in an attempt to measure the psychological reaction of the population to impending rainfall reflected as a reduction in lawn irrigation. The parameter then becomes:

$$\frac{\text{Total Rainfall in inches}}{\text{No. of days with Rainfall} \geq 0.01''} \times \text{Average Sky Cover}$$

Where: The average sky cover is an arbitrary scale from 0 to 10.

U. S. Weather Bureau data containing these factors are available for only the larger cities. On this basis, 16 cities in Texas were selected for this study. These include the large population centers in the Trinity River basin study area as well as others throughout the State encompassing a great variety of climates ranging from arid to semiarid to coastal.

The data for the years 1954, 1956, 1957, and 1959 were collected for each of the cities and a climate factor calculated for each year. This gave 64 points which were plotted against per capita consumption for the same years and cities as shown in Figure A-4.

Although far from perfect, the correlation here was appreciably better than any observed with the parameters in 1, 2, and 3 above. Other plots were made of the factors comprising the climate factor singly and in other combinations, each of which displayed an appreciable decrease in correlation with per capita consumption of water.

Projecting Municipal Water Use Factors

The projection of municipal per capita water use factors does not lend itself to simple mathematical analysis. The several items considered in making projections for this study are as follows:

1. Past Records. The past per capita use figures for Dallas, Fort Worth, and Houston are shown in Figure A-5. A definite upward trend is evident

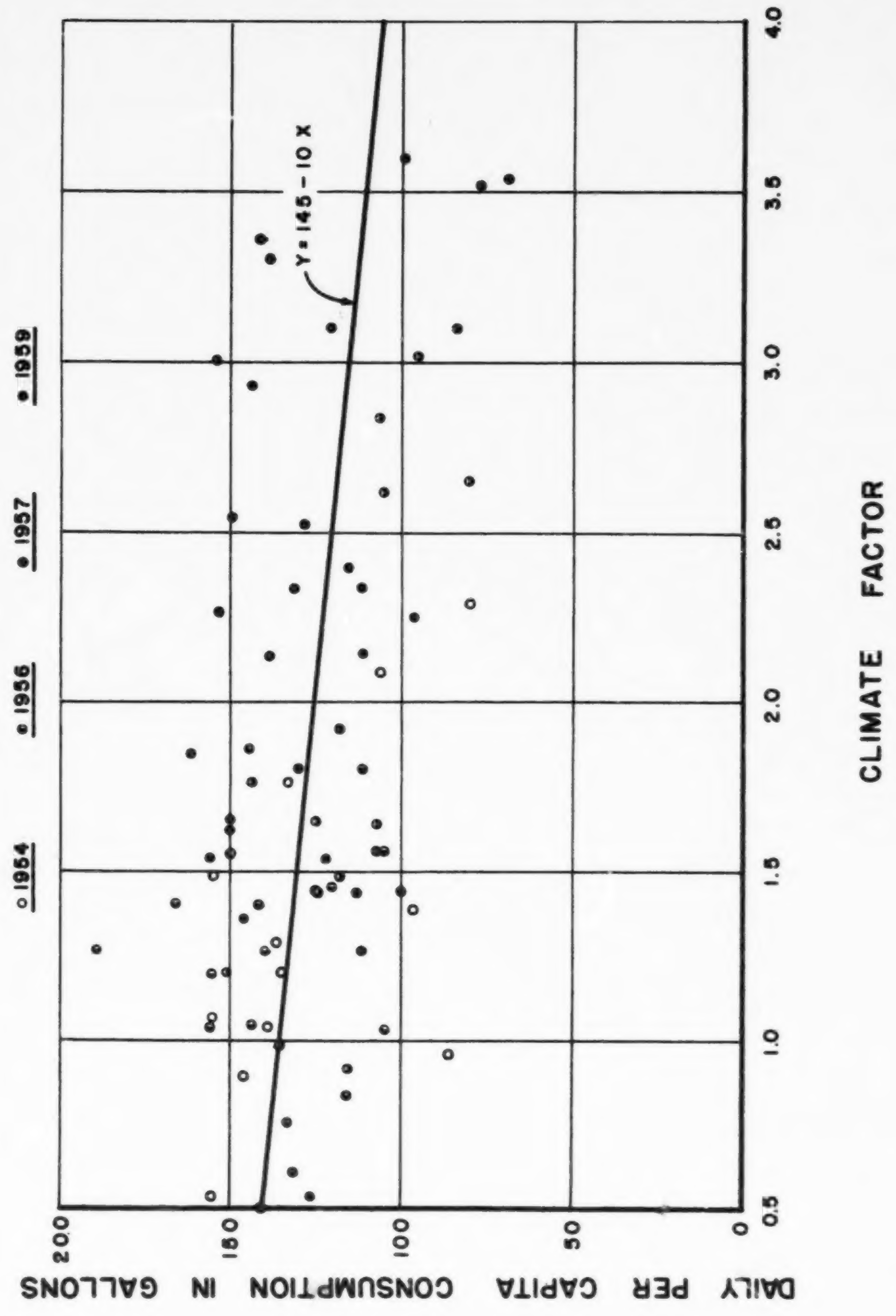


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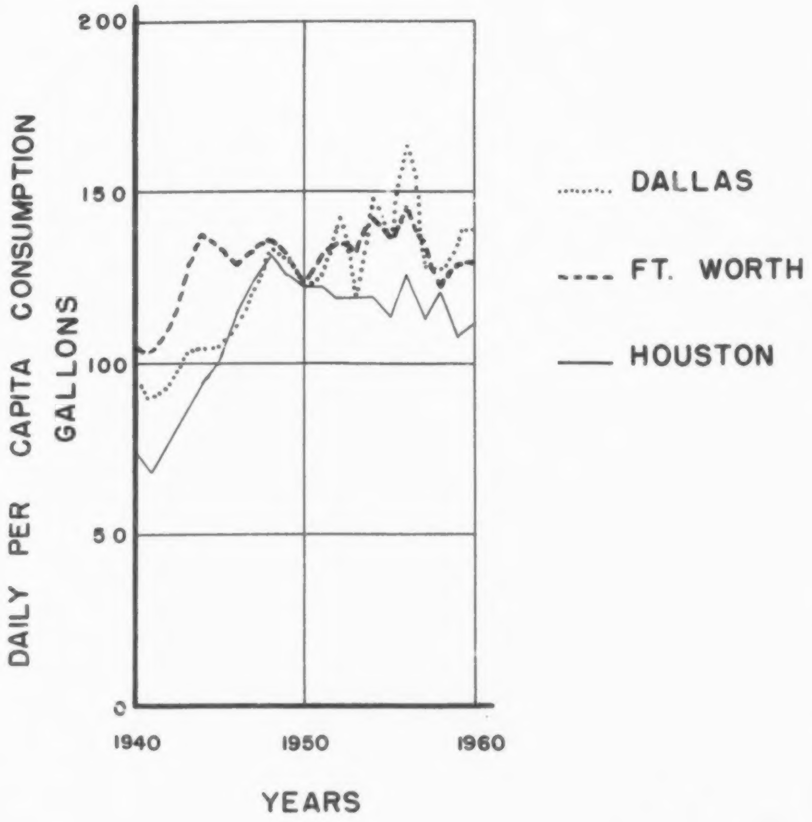
FIGURE A-4



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MUNICIPAL PER CAPITA
WATER USE STUDY

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
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FIGURE A-5

here with annual fluctuations as may be expected in any record of this kind. The average annual gain in gpcd calculated from these records is:

Dallas	1.75 gal./year
Fort Worth	1.32 gal./year
Houston	0.80 gal./year

The record of per capita consumption in Houston is questionable due to the large numbers of private supplies for which no records are available. No long-term records were available for the small towns.

2. Annual Precipitation. As previously discussed, annual rainfall seems to influence per capita consumption between certain ranges. For purposes of projection, that portion of the per capita consumption attributable to variation in precipitation is assumed constant for a particular locality. Although some increase is expected as cities grow, due to new suburban developments, this can be expected to stabilize and come back to present levels as lawns become established and suburban population densities increase.

3. Characteristics of the Subarea. This item comprises several factors peculiar to each subarea. Included are: (a) per capita income; (b) industrial consumption by small organizations whose water use is inseparable from municipal use figures; and (c) water use by service industries.

4. Analysis of Projections by Others. Projections and forecasts made by other government agencies, consulting engineers, and the municipalities themselves are worthy of consideration and study.

5. Judgment. After all of the above factors have been considered and weighed, discrepancies which inevitably exist must be resolved by judgment. The bases for credibility of the judgment involved in the final analysis are past experience in, knowledge of, and insight into the problems by the persons responsible.

For purposes of this study, a factor for municipal per capita consumption of source water was adopted, which includes all treatment and distribution losses. Table A-1 below shows the factors for the base year, 1958, and the terminal year of the study, 2020. Base year values were determined from the sources previously discussed.

Table A-1

Municipal Per Capita Water Use (Excluding all Industrial)

	County	Municipal Per Capita Consumption in Gal./Day	
		1958	2020
1.	Anderson	125	160
2.	Archer	85	175
3.	Brazoria	93	150
4.	Chambers	81	150
5.	Clay	78	170
6.	Collin	95	165
7.	Cooke	125	170
8.	Dallas	117	175
9.	Delta	67	155
10.	Denton	94	175
11.	Ellis	89	170
12.	Fannin	111	155
13.	Fort Bend	116	155
14.	Freestone	86	165
15.	Galveston	101	150
16.	Grayson	147	170
17.	Hardin	103	150
18.	Harris	113	155
19.	Henderson	79	160
20.	Hill	84	170
21.	Hopkins	95	160
22.	Houston	98	155
23.	Hunt	94	155
24.	Jack	69	175
25.	Jefferson	72	145
26.	Johnson	103	170
27.	Kaufman	68	165
28.	Leon	106	165
29.	Liberty	80	155
30.	Limestone	94	165
31.	Madison	74	160
32.	Montague	76	165
33.	Montgomery	85	155
34.	Navarro	84	160
35.	Palo Pinto	100	180
36.	Parker	70	175
37.	Polk	78	150
38.	Rains	67	160
39.	Rockwall	64	165
40.	San Jacinto	133	155
41.	Tarrant	108	175
42.	Trinity	100	155
43.	Van Zandt	100	160
44.	Walker	122	160
45.	Wise	91	175
46.	Young	122	180

The county was selected as the political entity to be used in this study. This was considered to be the best unit because: (1) In the case of metropolitan centers, the large central city covers most of the county; (2) In rural districts, the towns and villages can be added together to provide a base large enough for statistical analysis; (3) Data for counties are readily available; and (4) The 46 counties of the study area are each small enough to be considered as a homogeneous unit from the standpoint of water use, water sources, climate, and economic evaluation.

Examination of Table A-1 will show that the range of per capita consumption throughout the study area has been decreased from 83 (64 to 147) gpcd in 1958 to 35 (145 to 180) gpcd in 2020. This results in a range of increases in per capita consumption between 1958 and 2020 for particular counties varying between 16 gpcd and 106 gpcd. The following assumptions in order of importance were made to justify the projections.

1. Discrepancies in base year data exist even after adjustments were made as indicated by field reconnaissance. The scope of this study did not warrant full investigation of each municipality in the study area, and the most probable sources of error are thought to be inaccuracies in measurement of water used, estimates of population served, and reporting of these data.

2. The study area will become less heterogenous if the expected growth in population and industry occurs within the projection period.

3. Base municipal per capita water use does not now and will not in the future vary considerably between municipalities within a small geographical area except as determined by the following modifying factors:

    a. A very small increase in gpcd with increase in size of city.

    b. Variations due to climatic conditions - especially precipitation.

    c. Minor variations relating to different levels of per capita income.

d. Minor variations with cost of delivered water. This is further restricted to periods of change of systems from unmetered to metered and to extremely high water rates. (Not expected in the study area.)

e. Variances in reported quantities due to poor measurement or large system losses, which are necessarily assumed constant for the projections.

Industrial Water Use

Base Year Unit Employee Water Use

The primary data source on industrial water use was the 1958 inventory of industrial water use prepared by the Bureau of Business Research, University of Texas. This was supplemented by the 1954 Census of Manufacturers.

Although the 1958 inventory contained data on all sizes of establishments, only those using 10 million gallons of water or more annually were considered in the first phase of the study. It was possible to obtain the names of the listed firms. These were then arranged by counties and the four-digit Standard Industrial Classification* Code, and data on employment were obtained from the Texas Employment Commission. The result was a unit water use per employee.

Water use was then further broken down as to source. These are: (1) municipally supplied, (2) surface water, (3) ground water, (4) other sources such as privately owned utilities, and (5) brackish water.

This procedure established several important facts, the most prominent being a large difference in unit employee water use for a single industrial category in different geographical locations within the study area. This was further strengthened by the census data for value added by manufacturing. When water use was divided by value added (gallons per dollar value added) for each county, and plotted on a map of the study area, a distribution pattern which closely followed the distribution of the unit employee water use was observed. This was done for total industry (SIC 13 through 39) as well as for each two-digit SIC category.

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* Standard Industrial Classification Manual, The Technical Committee on Industrial Classitication, Office of Statistical Standards, Executive Office of the President, Bureau of the Budget, Washington, D. C., 1957.

On the basis of the above, it was decided to use different unit employee water use figures for each county rather than single average area value for each industrial category. It was further decided that restriction of data to users of 10 MGY or more would result in too small a base for practical consideration. To obtain a broader base, therefore, all industrial water users regardless of size were considered. This gave approximately 85 per cent coverage of the area, and supplementary data for 1954 trended to 1958 and field work by the regional office staff provided the remainder.

Considerations involved in economic projections of the labor force required consolidation of some of the manufacturing categories into groups to obtain a larger base for the study. After careful consideration of the factors involved from the standpoint of economics as well as water use, the following breakdown for industry was established.

Table A-2

Industrial Breakdown

Item	SIC Categories
Mining, Total	13, 14
Petroleum	13
Other	14
Manufacturing	
Resource-Oriented	
Furniture, Lumber, and Wood	24, 25
Primary Metals	33
Food and Kindred Products	20
Chemicals and Allied Products	28
Stone, Shell, Clay, and Glass	32
Other Nondurables	
Petroleum	29
Pulp and Paper	26
Other	30, 31
Nonresource-Oriented	
Fabricated Metals, Machinery, Transportation Equipment and Instruments	34, 35, 36, 37, 38
Textiles and Apparel	22, 23
Printing and Publishing and Miscellaneous Manufacturing	27, 39

A unit employee water use for each of the industrial classifications above and for each of the 46 counties in the study area was then determined and is shown in Table A-3.*

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*Actual water use figures may deviate from some of the values shown in this table, due to the adjustment described in Assumption No. 1 of the Section on Industrial Water Use Projections which follows.

Table A-3

1958 Unit Industrial Water Use in Gallons per Employee Day

County	Mining Total (13,14)	Mining Petroleum (13)	Mining Other (14)	Furniture, Lumber, & Wood (24,25)	Primary Metals (33)	Food & Kindred (20)	Chemicals & Allied (28)	Stone, Clay, & Glass (32)	Petroleum (29)	Pulp & Paper (26)	Other Non-durables (30,31)	Fabricated Metals (34,35,36, 37,38)	Textiles & Apparel (22,23)	Printing & Publish NEC (27,29)
1. Anderson	627			130	2,098	300	3,000	165	4,000	2,319	200	80	10	20
2. Archer	25			30	25	300	600	370	750	25	45	80	10	20
3. Brazoria	1,076	353	13,608	320	2,098	1,277	11,412	1,465	4,954	2,500	151	102	68	20
4. Chambers	2,609	353		876	2,098	800	6,257	800	3,385	2,319	150	67	65	20
5. Clay	50			30	25	300	600	370	750	25	45	80	10	20
6. Collin	25			52	91	272	695	371	223	452	45	79	44	20
7. Cooke	50			50	80	300	600	370	225	100	45	80	40	20
8. Dallas	25			52	91	272	695	371	223	452	45	79	44	20
9. Delta	25			50	80	300	700	370	225	100	45	80	40	20
10. Denton	25			52	91	272	695	371	223	452	45	79	44	20
11. Ellis	25			52	91	272	695	371	223	452	45	79	44	20
12. Fannin	50			50	80	300	700	370	225	100	45	80	40	20
13. Fort Bend	1,076	353		320	2,098	1,277	1,131	1,465	4,954	2,500	151	102	68	20
14. Freestone	100			89	2,098	214	3,000	418	4,000	98	242	80	74	20
15. Galveston	1,076	353		320	2,098	1,277	11,412	1,465	4,954	2,500	151	102	68	20
16. Grayson	50			50	80	300	600	370	225	100	45	80	40	20
17. Hardin	2,609	353		876	312	800	6,257	800	3,385	2,319	150	67	65	20
18. Harris	1,076	353		320	2,098	1,277	1,131	1,465	4,954	2,500	151	102	68	20
19. Henderson	1,613		13,608	59	657	217	500	649	5,940	91	3,986	280	10	20
20. Hill	25			89	785	214	500	418	250	98	242	80	74	20
21. Hopkins	25			50	80	300	700	370	225	100	45	80	40	20
22. Houston	627			130	2,098	300	3,000	165	4,000	2,319	200	80	10	20
23. Hunt	25			52	91	272	695	371	223	452	45	79	44	20
24. Jack	25			13	22	384	2,154	370	764	22	47	85	11	20
25. Jefferson	2,609	353	13,608	876	312	800	6,257	800	3,385	2,319	150	67	65	20
26. Johnson	25			13	22	384	2,154	370	764	22	47	85	11	20
27. Kaufman	25			52	91	272	695	271	223	452	45	79	44	20
28. Leon	627			130	2,098	300	3,000	165	4,000	2,319	200	80	10	20
29. Liberty	1,076	353	13,608	320	2,098	1,277	6,257	1,465	4,954	2,500	151	102	68	20
30. Limestone	100			89	785	214	500	418	250	98	242	80	74	20
31. Madison	800			112	2,098	712	3,000	165	4,000	2,319	110	80	15	20
32. Montague	50			30	25	300	600	370	750	25	45	80	10	20
33. Montgomery	1,076	353		320	2,098	1,277	1,131	1,465	4,954	2,500	151	102	68	20
34. Navarro	25			52	91	272	695	371	223	452	45	79	44	20
35. Palo Pinto	25			13	22	384	2,154	370	764	22	47	85	11	20
36. Parker	25			13	22	384	2,154	370	764	22	47	85	11	20
37. Polk	1,076	353		320	2,098	800	6,257	800	3,385	2,319	150	67	65	20
38. Rains	25			52	91	272	695	371	223	452	45	79	44	20
39. Rockwall	25			52	91	272	695	371	223	452	45	79	44	20
40. San Jacinto	1,076	353		320	2,098	1,277	1,131	1,465	4,954	2,500	151	102	68	20
41. Tarrant	25			13	22	384	2,154	370	764	22	47	85	11	20
42. Trinity	800			706	2,098	307	6,000	467	4,000	2,500	150	99	17	20
43. Van Zandt	25			52	91	272	695	371	223	452	45	79	44	20
44. Walker	1,076	353		320	2,098	1,277	6,000	1,465	4,954	2,500	151	102	68	20
45. Wise	25			13	22	384	2,154	370	764	22	47	85	11	20
46. Young	25			13	22	384	2,154	370	764	22	47	85	11	20

Industrial Water Use Projections

In order to project industrial water use, the following assumptions were made:

1. In presently undeveloped counties, where large future developments are projected, the base year unit employee water uses are adjusted to those of surrounding counties whose present condition approaches that forecasted for the undeveloped county.

2. The difference in unit employee water use by geographical areas in a given industrial classification will not be materially affected by the passage of time. For example, in Dallas County, a large percentage of the employees shown in petroleum (SIC 29) are now and are expected in the future to be nonproduction workers. On the other hand, in some of the gulf coast counties, the majority of workers in this category are now and will in the future be production employees; hence, the variation in unit employee water use.

3. The average net "productivity factor" (i.e. the multiplier to obtain unit employee use for the year 2020 from 1960 data) is 2.0 determined as follows:

    The median projections of Resources for the Future, Inc., and the Business and Defense Service Administration taken from Senate Select Committee Print No. 8* for gallons per day per employee in the principal water-using industries were extrapolated to the year 2020 and a median curve constructed.

    This gave a value in 2020 of 26,500 gpd/employee, which when divided by the 1960 value from the same curve of 13,000 gpd/employee, gave the productivity factor of 2.0.

    Industrial water use projections are then obtained by multiplying the projected labor force by the unit uses shown in Table 2 and the productivity factor.

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*Water Resources Activities in the United States, Committee Print No. 8, "Future Water Requirements of Principal Water Using Industries," Eighty-Sixth Congress, Washington, D. C., 1960.

Water for Thermal Electric Power Generation

This use for water was treated separately because its projection was a function of the total population rather than the labor force.

Projection of KWH per capita day by the Federal Power Commission and the Edison Electric Institute as contained in Senate Select Committee Print No. 10*, were extrapolated to the year 2020, and a median curve constructed. This gave a use in the year 2020 of 60.5 KWH per capita day.

Data from power companies in the area, various consulting engineers, and Senate Select Committee Print No. 10 gave a median value of 0.8 gallons of water consumed per KWH in the year 2020.

Combining the two values above gave a unit use of 48.4 gallons per capita day which was adopted for the study.

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* Water Resources Activities in the United States, Committee Print No. 10, "Electric Power in Relation to the Nation's Water Resources," Eighty-Sixth Congress, Washington, D. C., 1960.

APPENDIX B

GROUND WATER INVESTIGATION

Base Year Use

The data on base year use were obtained from reports of operating wells compiled by the Texas Board of Water Engineers in the year 1958. The quantities were tabulated from punch cards on an IBM 407 and are listed by county and aquifer in Table B-1 [3] below. These figures represent the available information and do not infer total coverage of the study area.

Table B-1

1958 Ground Water Use by County and Aquifer

No. Wells	Total in Mil. Gals.	Av. Use (mgd)	Type of Use	Aquifer
			Anderson	
2	21.90	0.060	Mun.	Carrizo Sand
1	38.32	0.105	Mun.	Queen City Sand
2	2.74	0.007	Mun.	Queen City Sand-Wilcox Group
2	21.50	0.059	Ind.	Queen City Sand-Wilcox Group
4	574.00	1.572	Mun.	Wilcox Group
1	1.80	0.005	Ind.	Wilcox Group
			Brazoria	
35	1,997.29	5.464	Ind.	Alluvium
10	460.10	1.162	Mun.	Beaumont Clay
15	693.42	1.907	Mun.	Beaumont Clay-Alluvium
6	700.00	1.930	Ind.	Beaumont Clay-Alluvium
3	122.00	0.335	Ind.	Goliad-Willis-Lissie Sands
4	130.50	0.358	Mun.	Goliad-Willis-Lissie Sands-Beaumont Clay
11	1,655.66	4.536	Ind.	Goliad-Willis-Lissie Sands-Beaumont Clay
			Chambers	
4	94.68	0.252	Mun.	Beaumont Clay
			Collin	
1	45.00	0.150	Ind.	Paluxy Formation
3	40.00	0.110	Mun.	Trinity Sand
2	497.22	1.362	Ind.	Trinity Sand
6	49.33	0.135	Mun.	Woodbine Formation
2	36.50	0.100	Mun.	Woodbine & Paluxy Formation
			Cooke	
4	675.70	1.836	Mun.	Trinity Sand
2	49.25	0.151	Ind.	Trinity Sand
4	16.86	0.046	Ind.	Trinity Sand-Woodbine Formation

No. Wells	Total in Mil. Gals.	Av. Use (mgd)	Type of Use	Aquifer
Dallas				
5	44.29	0.127	Ind.	Alluvium
7	75.14	0.212	Mun.	Paluxy Formation
2	37.15	0.116	Ind.	Paluxy Formation
10	464.63	1.350	Mun.	Trinity Sand
11	706.18	2.121	Ind.	Trinity Sand
4	190.60	0.525	Mun.	Trinity Sand-Paluxy Formation
12	1,062.98	2.890	Ind.	Trinity Sand-Paluxy Formation
3	25.00	0.068	Mun.	Trinity Sand-Woodbine Formation
33	2,400.89	7.258	Mun.	Trinity Sand-Woodbine & Paluxy Formation
21	332.38	0.916	Mun.	Woodbine Formation
17	370.54	1.418	Ind.	Woodbine Formation
1	20.00	0.072	Ind.	Woodbine Formation-Alluvium
6	125.58	0.384	Mun.	Woodbine & Paluxy Formations
Denton				
4	23.32	0.064	Mun.	Paluxy Formation
19	230.93	0.249	Mun.	Trinity Sand
2	15.10	0.063	Ind.	Trinity Sand
5	79.00	0.216	Mun.	Trinity Sand-Paluxy Formation
2	35.00	0.096	Mun.	Trinity Sand-Woodbine Formation
Ellis				
4	33.36	1.017	Mun.	Trinity Sand
3	30.00	0.125	Mun.	Trinity Sand-Woodbine Formation
15	438.75	1.203	Mun.	Woodbine Formation
1	0.20	0.0006	Ind.	Woodbine Formation
Fannin				
1	1.20	0.004	Mun.	Trinity Sand
10	377.26	1.061	Mun.	Woodbine Formation
Fort Bend				
1	0.36	0.001	Ind.	Beaumont Clay
5	298.81	0.825	Mun.	Goliad-Willis-Lissie Sands
16	3,259.70	9.002	Ind.	Goliad-Willis-Lissie Sands
6	410.48	1.127	Mun.	Goliad-Willis-Lissie Sands-Beaumont Clay
2	52.56	0.144	Ind.	Lissie Sand
Freestone				
2	56.78	0.156	Mun.	Wilcox Group

No. Wells	Total in Mil. Gals.	Av. Use (mgd)	Type of Use	Aquifer
Galveston				
16	937.43	2.567	Mun.	Beaumont Clay
18	1,928.82	5.635	Ind.	Beaumont Clay
23	4,982.25	13.650	Mun.	Goliad-Willis-Lissie Sands-Beaumont Clay
Grayson				
3	87.67	0.240	Mun.	Trinity Sand
12	862.91	3.000	Mun.	Trinity Sand-Woodbine Formation
4	23.70	0.065	Ind.	Trinity Sand-Woodbine Formation
16	281.80	0.775	Mun.	Woodbine Formation
6	275.95	0.919	Ind.	Woodbine Formation
Hardin				
5	65.34	0.179	Ind.	Goliad & Lissie Sands
7	270.82	0.742	Mun.	Goliad-Willis-Lissie Sands-Beaumont Clay
Harris				
1	3.13	0.009	Ind.	Unknown
18	560.51	1.536	Mun.	Beaumont Clay
30	5,500.94	14.968	Ind.	Beaumont Clay
1	131.40	0.360	Ind.	Goliad & Lissie Sands-Beaumont Clay-Alluvium
2	11.17	0.032	Mun.	Goliad-Willis-Lissie Sands
82	17,431.38	51.321	Ind.	Goliad-Willis-Lissie Sands
111	28,615.88	100.286	Mun.	Goliad-Willis-Lissie Sands-Beaumont Clay
33	7,356.47	20.151	Ind.	Goliad-Willis-Lissie Sands-Beaumont Clay
103	7,026.66	19.250	Mun.	Lissie Sand
49	5,483.72	15.025	Ind.	Lissie Sand
7	298.20	0.817	Mun.	Lissie Sand-Beaumont Clay
1	2.30	0.006	Ind.	Lissie Sand-Beaumont Clay
--	5.48	0.015	Mun.	Willis Sand-Lissie Sand
Henderson				
2	339.18	0.943	Mun.	Wilcox Group
13	168.97	0.463	Ind.	Wilcox Group
Hill				
9	184.70	0.575	Mun.	Trinity Sand
4	33.00	0.120	Mun.	Trinity Sand-Woodbine Formation
10	241.31	0.661	Mun.	Trinity Sand-Woodbine & Paluxy Formation

No. Wells	Total in Mil. Gals.	Av. Use (mgd)	Type of Use	Aquifer
Hill (Continued)				
1	1.02	0.003	Mun.	Woodbine Formation
Hopkins				
2	18.00	0.049	Mun.	Nacatoch Sand
--	1.94	0.005	Mun.	Wilcox Group
Houston				
2	48.62	0.133	Mun.	Carrizo Sand
1	0.18	0.001	Ind.	Carrizo Sand
3	361.35	0.990	Mun.	Sparta Sand
2	14.00	0.038	Mun.	Yegua Formation
Hunt				
5	195.18	0.535	Mun.	Nacatoch Sand
4	21.46	0.059	Mun.	Woodbine Formation
Jack				
3	8.76	0.024	Mun.	Canyon Group
22	14.60	0.040	Mun.	Cisco Group
4	6.13	0.017	Ind.	Cisco Group
Jefferson				
15	879.68	2.409	Ind.	Beaumont Clay
Johnson				
7	67.46	0.185	Mun.	Paluxy Formation
8	536.12	1.469	Mun.	Trinity Sand
1	0.27	0.001	Ind.	Trinity Sand
6	107.89	0.296	Mun.	Trinity Sand-Paluxy Formation
4	34.68	0.095	Mun.	Woodbine & Paluxy Formations
Kaufman				
2	27.38	0.075	Mun.	Woodbine Formation
Leon				
3	27.19	0.075	Mun.	Carrizo Sand
2	36.50	0.100	Mun.	Queen City Sand
2	36.00	0.100	Mun.	Wilcox Group
Liberty				
3	90.00	0.250	Mun.	Beaumont Clay
2	3.50	0.010	Ind.	Beaumont Clay
3	120.00	0.329	Mun.	Catahoula Tuff-Oakville Sandstone & Lagarto Clay
2	8.64	0.024	Mun.	Goliad-Willis-Lissie Sands

No. Wells	Total in Mil. Gals.	Av. Use (mgd)	Type of Use	Aquifer
Liberty (Continued)				
1	1.00	0.006	Ind.	Goliad-Willis-Lissie Sands
2	215.72	0.591	Mun.	Goliad-Willis-Lissie Sands-Beaumont Clay
4	9.92	0.037	Ind.	Goliad-Willis-Lissie Sands-Beaumont Clay
6	8.93	0.035	Ind.	Catahoula-Oakville-Lagarto-Goliad-Willis-Lissie Sands
Limestone				
7	296.00	0.750	Mun.	Nacatoch Sand
Madison				
4	132.61	0.363	Mun.	Yegua Formation
Montague				
16	79.89	0.219	Mun.	Cisco Group
5	1.32	0.004	Ind.	Cisco Group
3	22.51	0.062	Mun.	Trinity Sand
Montgomery				
5	390.16	1.069	Mun.	Catahoula Tuff-Oakville Sandstone-Lagarto Clay
1	10.00	0.028	Ind.	Goliad Sand-Lissie Sand
1	0.002	0.00005	Ind.	Ogallala Formation
11	448.89	1.228	Ind.	Catahoula-Oakville-Lagarto-Goliad-Willis-Lissie Sands
Navarro				
1	24.09	0.066	Mun.	Trinity Sand
3	29.89	0.082	Mun.	Woodbine Formation
Palo Pinto				
1	0.12	0.0003	Ind.	Strawn Group
Parker				
2	47.30	0.130	Ind.	Trinity Sand
Polk				
7	64.04	0.178	Mun.	Catahoula Tuff-Oakville Sandstone-Lagarto Clay
2	43.80	0.120	Mun.	Jackson Group
2	122.90	0.337	Mun.	Lagarto Clay
Rains				
1	16.50	0.045	Mun.	Wilcox Group

No. Wells	Total in Mil. Gals.	Av. Use (mgd)	Type of Use	Aquifer
			Rockwall	
1	2.74	0.008	Mun.	Trinity Sand
			San Jacinto	
1	0.73	0.002	Mun.	Catahoula Tuff-Oakville Sandstone-Lagarto Clay
			Tarrant	
1	1.84	0.005	Mun.	Glen Rose Limestone
36	361.70	1.018	Mun.	Paluxy Formation
17	76.07	0.218	Ind.	Paluxy Formation
17	188.84	0.644	Mun.	Trinity Sand
20	988.67	3.374	Ind.	Trinity Sand
31	436.44	1.200	Mun.	Trinity Sand-Paluxy Formation
8	314.90	0.926	Ind.	Trinity Sand-Paluxy Formation
4	35.00	0.096	Mun.	Trinity Sand-Woodbine Formation
74	2,517.61	6.939	Mun.	Trinity Sand-Woodbine Formation-Paluxy Formation
1	0.60	0.004	Ind.	Woodbine Formation
			Trinity	
5	171.70	0.470	Mun.	Jackson Group
			Van Zandt	
3	68.31	0.187	Mun.	Wilcox Group
			Walker	
8	534.73	1.465	Mun.	Catahoula Tuff-Oakville Sandstone-Lagarto Clay
			Wise	
1	31.59	0.865	Mun.	Carrizo Sand
5	39.19	0.107	Mun.	Paluxy Formation
7	118.81	0.324	Mun.	Trinity Sand
6	53.52	0.140	Ind.	Trinity Sand
3	5.48	0.015	Mun.	Trinity Sand-Paluxy Formation
			Young	
1	1.53	0.004	Mun.	Cisco Group
1	4.54	0.013	Ind.	Seymour Formation
1,385	112,819.71	339.449	-- TOTALS	

In his study of the ground water resources of the study area, Mr. William O. George compiled the following descriptions of the resource by subarea.

Ground Water Resources of Subarea 1

Subarea 1, which includes Clay, Jack, Archer, Young, and Palo Pinto Counties, yields very little ground water, and the potential yield is also small as compared with counties in the coastal area of the Trinity River basin.

The rocks underlying the area are of Pennsylvanian and Permian age and of the Paleozoic era, which contain no major aquifers.

The Wichita group of the Permian system crops out in Archer and Clay Counties. Yields are small and the quality of the water is generally poor.

The Strawn, Canyon, and Cisco groups yield small quantities of water near the outcrops but in most places the water becomes more highly mineralized down dip.

The estimated potential yield for the year 2020 is 2.6 mgd. It is believed that this yield is adequate for satisfying non-municipal requirements.

Ground Water Resources of Subarea 2

The ground water potential in Subarea 2 is much greater than that of Subarea 1 because of the overlap of sands in the Trinity group of Cretaceous age from the east. The three counties are similar in this respect except that the overlap is increasingly greater southward.

The yields from the underlying Paleozoic rocks are relatively small in all three counties. The waters of the Trinity sands are of fair quality to a depth of 4,000 feet.

The estimated potential yield for the subarea in the year 2020 is about 79 mgd.

Ground Water Resources of Subarea 3

Ground water in Subarea 3 is supplied mainly by aquifers in the Trinity group and the Woodbine formation. An undetermined amount of ground water occurs in the Alluvium along the Trinity River bottoms.

In Cooke County the formations strike north-northeast and thence eastward around the north end of the Sherman syncline in Grayson County. In Cooke County the sands of the Trinity group crop out along the western margin of the county; the Woodbine crops out along the eastern county line; the area between being covered by the relatively impervious members of the Washita group.

There are known yields of from 400 to 600 gallons per minute of good quality water from wells 2,295 feet deep in the Trinity sands.

The estimated potential yield for the year 2020 is 45 mgd.

Ground Water Resources of Subarea 4

Subarea 4 occupies an area where ground water of good quality is relatively scarce. Most of the aquifers are too deep or the water in them is too highly mineralized. Most of the municipalities use impounded surface water which is of excellent chemical quality.

It is believed that prospecting would reveal a considerable volume of water in the Alluvium along the main streams, but no records are available.

The estimated potential yield for the year 2020 is 7.6 mgd.

Ground Water Resources of Subarea 5

Ground water resources in Subarea 5 are in the aquifers of the Tertiary age. The Carrizo-Wilcox is the major aquifer but, because of their wide distribution in the subarea, the combined yield of the Sparta and the Queen City may exceed that of the Carrizo-Wilcox.

The water of the Carrizo-Wilcox is of exceptionally good chemical quality to a depth of 1,100 feet. The water of the Queen City and Sparta aquifers is also of good quality, but may contain excessive amounts of iron in some places.

The estimated potential yield of ground water in 2020 is 234.3 mgd.

Ground Water Resources of Subarea 6

With the exception of Leon County, most of the counties in Subarea 6 are relatively poor in ground water. Navarro and Limestone Counties lie between the Cretaceous and Tertiary aquifers. Leon County can be well supplied by the Carrizo-Wilcox aquifer as well as some of Madison County, but in Madison County the Carrizo-Wilcox is fairly deep and the quality of the water may not be acceptable for public supply. However, the Carrizo should be encountered at approximately the same depth as at Bryan where Carrizo-Wilcox is used for public supply.

The estimated potential yield for the year 2020 is 298.9 mgd.

Ground Water Resources of Subarea 7

The overlapping of the Coastal sands on the Miocene sands permit large yields of excellent quality to a depth of 3,600 feet.

The estimated potential yield for the year 2020 is 925.5 mgd.

Ground Water Resources of Subarea 8

In Subarea 8, the Trinity sand is the main aquifer; the Paluxy sand and the Woodbine sands are also available. Tarrant and Johnson Counties are geologically similar in that the rocks are of the same age and dip eastward. In general the sands are tight and the yields are not large. The Woodbine sands are available only in the eastern part of the subarea. The Trinity sands are known to supply water of acceptable quality to a depth of about 1,775 feet.

The estimated potential yield for the year 2020 is 80 mgd.

Ground Water Resources of Subarea 9

Subarea 9 lies entirely within the belt of Cretaceous aquifers and for the most part is supplied by the Trinity sands. In the eastern part of the subarea, the Trinity sands become too deep and probably too highly mineralized for most purposes. The water in the upper Woodbine is generally too highly mineralized for public supplies.

The estimated potential yield for the year 2020 is 110 mgd.

Ground Water Resources of Subarea 10

Subarea 10 contains the most extensive underground reservoirs and the greatest potential yield of ground water of all the subareas in the study area. In 1954, 457.2 mgd were pumped from the ground water reservoirs of the subarea. In the greater part of the area, most of the wells are capable of discharging more than a million gallons a day. In a small area in the vicinity of Galveston, the ground water contains chlorides in excess of 500 parts per million. The greatest decline in water levels has occurred in the Pasadena area in Harris County where the decline in the 1931-1953 period was about 200 feet. Water levels have recovered somewhat since the introduction of surface water into the Houston system.

Aquifers in the subarea include the Goliad-Willis-Lissie sands of Pliocene and Pleistocene age and the Alta Loma sand of the Beaumont formation which overlap the Catahoula-Oakville-Lagarto aquifer of Miocene age. In some places more than 1,200 feet of fresh water bearing sands lie between the surface and a depth of 3,500 feet.

The estimated potential yield for the year 2020 is 1,087 mgd.

APPENDIX C

DETERMINATION OF WATER QUALITY

General

The determination of water quality takes into consideration the wastes which will result from the economic development of an area and the effects of these wastes on stream regimen. At any point in a stream, the water quality will be the result of mixing various qualities and quantities of water which make up the total flow modified by forces such as reaeration and evaporation which tend to change its character.

A comprehensive study of water quality requires consideration of a large number of individual contaminants which occur in most streams. For long-term planning, however, it is not considered necessary to make detailed studies of this nature. Estimates of pollution are based on water use as a logical outgrowth of present conditions and technology. To assign values to a multiplicity of waste constituents would create an apocryphal condition without any degree of probability. Therefore, quality analysis is based on broad parameters which are currently available for evaluation of future stream conditions. Total dissolved solids projections are employed to characterize the effects of stable pollutants (those constituents which are not utilized or reduced by stream environment). Dissolved oxygen content is applied as a measure of unstable pollutants (those constituents which decay and act on, or are acted on by the stream environment).

Stream Loading

An estimate of waste loads likely to be discharged to the stream in the future is the first step necessary in forecasting water quality conditions.

The waste characteristics were calculated from factors developed by the U. S. Study Commission-Texas in their appraisal of eight Texas river basins with modifications as required in this study. See Table C-1. [21,22]

The expected municipal and industrial return flows at the proposed navigation locks and dam sites for the years 1970 and 2020 are shown in Table C-2.

Table C-1

Factors Pertinent to the Determinations of Waste Loads

Waste Identification	Return Flow % of Intake	Untreated BOD (Unstable Characteristics)	Total Dissolved Solids (Stable Characteristics)
Municipal	41.2 to 82.5[21/]	0.25 lb./capita day	0.23 lb./capita day
Industrial			
Mining	44	1.55 Tons/mil. gal. returned	12.2 Tons/mil. gal. returned
Furniture, Lumber and Wood	90	0 Tons/mil. gal. returned	1.22 Tons/mil. gal. returned
Primary Metals	23	0 Tons/mil. gal. returned	12.2 Tons/mil. gal. returned
Food & Kindred Products	88	1.55 Tons/mil. gal. returned	7.30 Tons/mil. gal. returned
Chemicals & Allied Products	65	1.55 Tons/mil. gal. returned	1.22 Tons/mil. gal. returned
Stone, Clay and Glass Products	33	0 Tons/mil. gal. returned	1.22 Tons/mil. gal. returned
Petroleum Refining	67	1.55 Tons/mil. gal. returned	1.22 Tons/mil. gal. returned
Paper & Allied Products	90	1.55 Tons/mil. gal. returned	1.22 Tons/mil. gal. returned
Fabricated Metals	79	0 Tons/mil. gal. returned	1.22 Tons/mil. gal. returned
Textiles & Apparel	81	1.55 Tons/mil. gal. returned	1.87 Tons/mil. gal. returned
Printing, Publishing and N.E.C.	50	0 Tons/mil. gals.returned	1.22 Tons/mil. gal. returned
Miscellaneous Non-durables	79	0 Tons/mil. gal. returned	1.22 Tons/mil. gal. returned

Table C-2

Net Cumulative Municipal and Industrial Return Flows At Navigation Locks and Dams for 1970 and 2020 in MGD

Location River Mile	Net Return Flow		Location River Mile	Net Return Flow	
	1970	2020		1970	2020
536.5	0	0	248.1	167.1	287.1
524.8	62.5	147.9	199.8	170.7	303.4
510.1	62.5	147.9	Livingston	186.7	325.2
498.2	70.3	207.9	129.0	186.7	348.9
480.5	141.3	327.6	126.0	186.7	348.9
471.8	146.3	329.9	93.5	194.7	384.2
465.5	146.3	329.9	61.4	194.7	384.2
451.6	153.7	310.0	40.3	230.1	365.2
433.0	153.7	310.0	3.8	230.1	365.2
416.2	153.7	310.0			
386.1	153.7	292.0			
Tennessee Colony	164.4	300.9			
339.2	164.4	300.9			
338.3	164.4	300.9			
310.4	164.4	300.9			
283.5	164.5	301.2			

NOTE: Irrigation requirements from municipal and industrial return flows have been subtracted.

Additional assumptions concerning this study are:

1. Sufficient treatment will be provided to remove 90 percent of the biochemical oxygen demand and 15 percent of the total dissolved solids.

2. Evaporation and seepage from streams are reflected in stream flow records requiring no adjustment. Adjustments for evaporation in reservoirs were necessary, however.

3. Uniform mixing of wastes and receiving waters will occur.

4. Water for quality control is required when the dissolved oxygen content of the mixed water in the stream is below 4.0 milligrams per liter (mg/l.) or the total dissolved solids exceed 1,000 mg/l.

Methods of Calculation

Dissolved Oxygen

After determining the amounts, concentrations, and points of loading of the waste flow, a schematic diagram of the basin is prepared and analyses are made to calculate the quality of the resultant water in the stream. The results are expressed in terms of biochemical oxygen demand and dissolved oxygen, versus time of travel and river mileage. The calculations are based on the oxygen sag curve equation and, in the interest of time and accuracy, were performed on a Bendix G-15 computer. Computations are repeated at specified time intervals and the computer automatically determines the dissolved oxygen and biochemical oxygen demand at each interval based on a specified percentage removal of organic constituents by treatment, as previously discussed. Also, the amount of water or additional treatment required to maintain a preset minimum dissolved oxygen content are calculated for each reach of stream.

The assumption was made that undesirable effects of organic pollutants in a stream would be dissipated when these waters entered a large reservoir. Therefore, analyses are made only for reaches of stream with an imposed pollution load upstream from and between reservoirs.

By making calculations for each reach of stream by months, it was possible to determine the total annual, maximum, and minimum monthly, and average annual amounts of water required to maintain at least 4.0 mg/l. of dissolved oxygen in all reaches of stream studied. Factors for use in the computations, along with certain other assumptions, are shown in Table C-3. The schematic diagram of the basin used for the organic pollution studies is shown in Figure C-1.

Total Dissolved Solids

Total dissolved solids at any time and point in a flowing stream are a function of:

1. The quantity of mixed water.
2. The total volume of solids (i.e., solids in the stream runoff, plus the solids added by use, plus the solids in the user's source water).

Therefore, by performing a series of weighted averages in the direction of the system flow, the quantity and quality of water at any point in the system were determined. In a reservoir, however, the total dissolved solids are the result of a constantly changing situation over a period of years beginning when the reservoir is filling for the first time. Limitations on time and the uncertainties present in long-range studies make calculations of this kind impractical. It was decided, therefore, that it would be sufficient to consider the period immediately preceding the critical year used in the determination of reservoir yields. An examination of records showed that a drouth such as existed from 1941 to 1957 would create the most critical conditions, and conditions similar to those that existed in 1956 would be the most critical year. Thus the mineral quality projections are based on the most critical conditions. Obviously, if satisfactory conditions exist during this period, they will exist during all other periods.

It was assumed that the mineral concentration of the runoff entering a given reservoir at the time of the last uncontrolled spill prior to the critical year would be the starting concentration of minerals in the reservoir. During this time, waters would flow into the reservoir and be affected by evaporation and other factors which would tend to concentrate the minerals since there would be no opportunity for the reservoir to purge itself through spills.

Calculations were made to estimate the concentration of minerals in the reservoir at the beginning of the critical year. These were followed by monthly calculations for the critical year using data applicable to that year. That is, the assumptions were made that the projected future loads would be placed in the stream during a drouth period similar to that which occurred in 1956 with a reservoir in place and operated in a manner as shown in the water supply plan previously discussed in Section VII.

Table C-3

Organic Pollution Study Factors

1. **Temperatures.** The same temperatures are used throughout the basin. Fresh water temperatures were obtained from USGS WSP's and the pollution temperatures from records of the Fort Worth, Dallas, and Houston STP's.

Month	Temperature in °C. Fresh Water	Temperature in °C. Pollution Load
Jan.	10	15
Feb.	10	15
Mar.	15	16
Apr.	20	17
May	25	21
Jun.	28	25
Jul.	29	28
Aug.	29	28
Sep.	26	27
Oct.	23	25
Nov.	14	22
Dec.	10	15

2. Reaeration Factor @ 20°C. (F_{20})*

All Tributaries: F_{20}= 2.0
Main Stem above RM 550: F_{20}= 2.0
Main Stem below RM 550: F_{20}= 1.0

*After STREAM SANITATION by Phelps

3. Velocities of the Stream in mi./day
These quantities were obtained from travel times furnished by the Corps of Engineers and from estimates of velocity made by examination of flow records in USGS WSP's.

All tributaries except the East Fork: V=24 mi./day
East Fork of the Trinity River: V=18 mi./day
Main Stem above RM 550: V=24 mi./day
Main Stem below RM 550: V=6 mi./day (Navigation canal begins)

4. Runoff Factors in CFS/sq.mi.
These data were derived from flow records furnished by the Corps of Engineers in conjunction with the work of the U. S. Study Commission-Texas. The factors vary for the several subdrainage areas as well as for each month. They are tabulated on the attached sheet.

5. Contributing Drainage Areas in Square Miles.
These areas were determined from the Trinity basin drainage area compiled by the U. S. Study Commission-Texas.

Table C-3 (Continued)

Organic Pollution Study Factors

6. **Percent Treatment.** Ninety (90) percent removal of BOD has been assumed throughout the entire river basin.

7. **Time Interval in Days.** This is the time elapsed from the beginning of a reach at which the computer calculates values for the BOD and DO. It was generally taken to be 0.2 day except where it became evident that the DO would not go below 4.0 mg/l.

8. **Critical Period.** The year 1956 was chosen as the critical period for all factors pertaining to the elements. Computations were made for each month of this year.

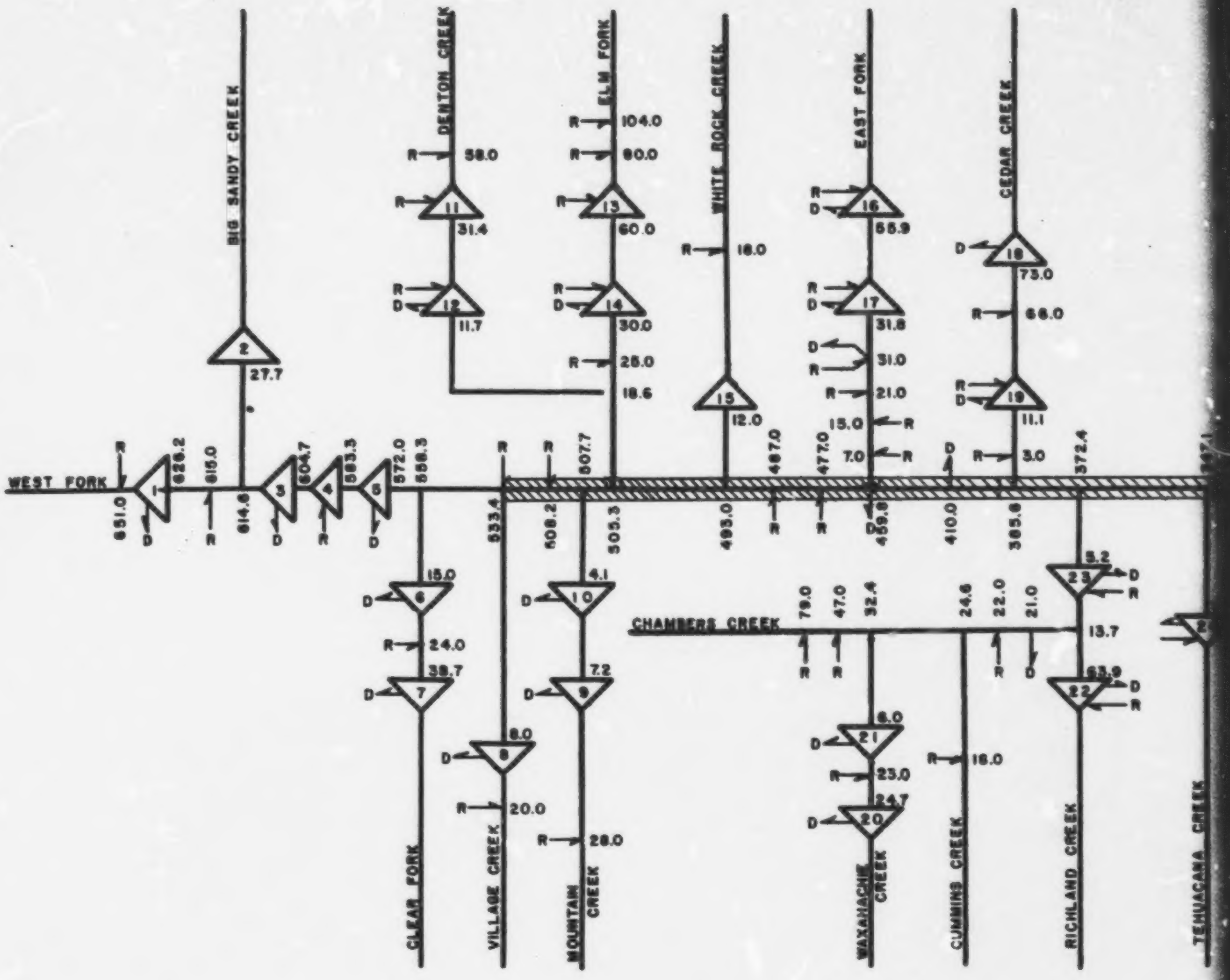
Month	Runoff Factors in CFS per square mile																	
Code	101	103	104	105	211	301	302	303	411	501	502	601	662	603	701	811	911	912	903
Jan.	.035	.059	.000	.063	.000	.000	.000	.019	.076	.016	.016	.019	.014	.014	.000	.166	.122	.057	.167
Feb.	.048	.184	.116	.376	.000	.048	.000	.093	.221	.312	.312	.097	.089	.089	.394	.331	.000	.063	.000
Mar.	.010	.044	.107	.196	.000	.000	.000	.027	.051	.016	.016	.000	.000	.000	.197	.466	.122	.000	.000
Apr.	.023	.065	.306	.419	.000	.024	.000	.102	.051	.000	.000	.000	.000	.000	.394	.331	.244	.000	.502
May	.000	.466	.000	.058	.091	.014	.000	.442	.476	.477	.477	.174	.231	.231	.000	.000	.122	.436	.000
Jun.	.000	.040	.066	.027	.000	.024	.000	.056	.034	.000	.000	.029	.024	.024	.000	.166	.000	.006	.000
Jul.	.000	.000	.026	.031	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Aug.	.015	.007	.017	.000	.051	.000	.000	.025	.000	.000	.000	.019	.007	.007	.000	.000	.000	.000	.000
Sep.	.000	.000	.017	.000	.000	.024	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Oct.	.000	.007	.017	.000	.000	.000	.000	.025	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Nov.	.000	.082	.000	.011	.000	.000	.000	.054	.094	.230	.230	.136	.102	.102	.000	.000	.000	.000	.167
Dec.	.079	.024	.046	.065	.000	.024	.000	.042	.017	.016	.016	.019	.009	.009	.000	.000	.000	.063	.000

Table C-3 (Continued)

Organic Pollution Study Factors

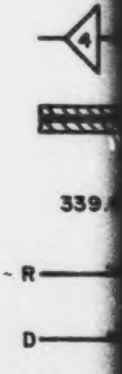
EXPLANATION OF CODE:

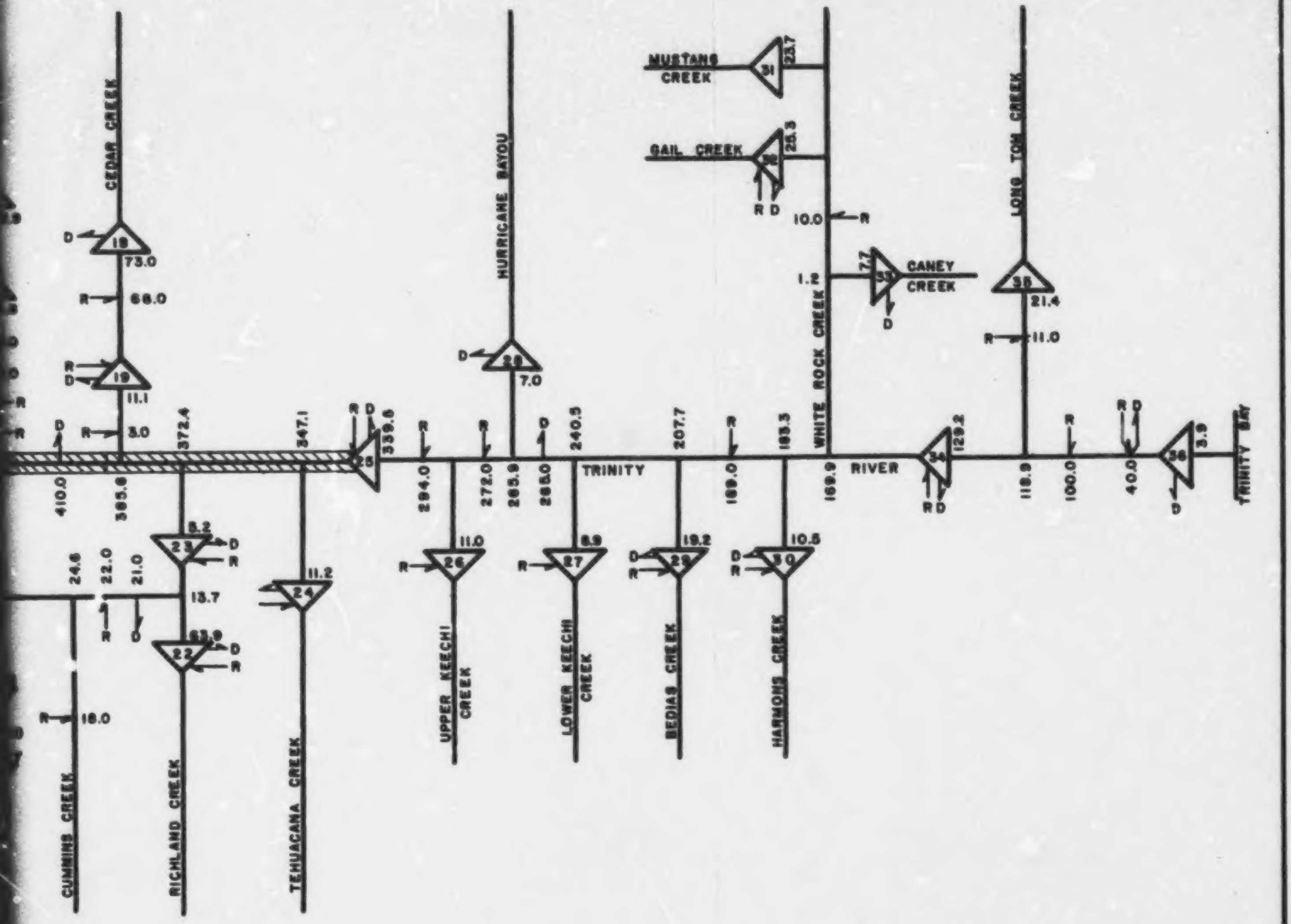
TRIBUTARY	LOCATION	CODE
West Fork	Bridgeport Res. to Boyd Res.	101
	Lake Worth to Tenn. Col. Res.	103
Clear Fork	Weatherford Res. to Benbrook Res.	211
Elm Creek	Denton Cr. above Roanoke Res.	301
	Elm Cr. above Aubrey Res.	302
	Garza-Little Elm Dam to West Fork	303
East Fork	Forney Res. to West Fork	411
Cedar Creek	Terrell Res. to Cedar Cr. Res.	501
	Cedar Cr. Res. to Tenn. Col. Res.	502
Chambers Creek	Waxahachie Res. to Bardwell Res.	601
	Cummins Creek	662
	Chambers Creek	603
White Rock Creek	Mustang Res. to Livingston	701
Long Tom Creek	Long King Res. to Trinity River	811
Ft. Worth-Dallas Area	Village Cr. to Lake Arlington	911
	Mountain Cr. to Lakeview	912
	White Rock Cr. to White Rock Lake	903
Trinity River	Tennessee Colony Res. to Livingston Res.	104
	Livingston Res. to Salt Water Barrier	105


WEST FORK
BIG SANDY CREEK
DENTON CREEK
ELM FORK
WHITE ROCK CREEK
EAST FORK
CEDAR CREEK
CHAMBERS CREEK
CLEAR FORK
VILLAGE CREEK
MOUNTAIN CREEK
WAXAHACHIE CREEK
CUMMINS CREEK
RICHLAND CREEK
TEHUACANA CREEK
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
R
D
651.0
626.2
615.0
614.6
604.7
593.3
572.0
558.3
533.4
508.2
507.7
505.3
493.0
487.0
477.0
459.8
410.0
385.8
372.4
27.7
58.0
31.4
11.7
104.0
80.0
60.0
30.0
25.0
18.6
16.0
12.0
55.9
31.8
31.0
21.0
15.0
7.0
73.0
66.0
11.1
3.0
15.0
24.0
38.7
8.0
20.0
4.1
7.2
28.0
79.0
47.0
32.4
24.6
22.0
21.0
5.2
13.7
63.9
6.0
23.0
24.7
18.0

KEY

1. BRIDGEPORT
2. AMON CARTER
3. BOYD
4. EAGLE MOUNTAIN
5. LAKE WORTH
6. BENBROOK
7. WEATHERFORD
8. LAKE ARLINGTON
9. LAKEVIEW
10. MOUNTAIN CREEK
11. ROANOKE
12. GRAPEVINE
13. AUBREY
14. GARZA-LITTLE ELM
15. WHITE ROCK LAKE
16. LAVON
17. FORNEY
18. LAKE TERRELL
19. CEDAR CREEK
20. WAXAHACHIE
21. BARDWELL
22. NAVARRO MILLS
23. RICHLAND
24. TEHUACANA
25. TENNESSEE COLONY
26. UPPER KEECHI
27. LOWER KEECHI
28. HURRICANE
29. BEDIAS
30. HARMONS
31. MUSTANG
32. GAIL
33. CANEY
34. LIVINGSTON
35. LONG KING
36. WALLISVILLE




CEDAR CREEK
D
19
73.0
R
68.0
R
D
19
11.1
R
3.0
D
410.0
385.8
372.4
8.2
23
D
R
24.6
22.0
21.0
13.7
R
D
63.9
22
D
R
R
18.0
CUMMINS CREEK
RICHLAND CREEK
347.1
11.2
24
TEHUACANA CREEK
R
D
339.6
25
R
294.0
11.0
26
R
UPPER KEECHI CREEK
R
272.0
HURRICANE BAYOU
D
28
7.0
265.9
D
265.0
240.5
TRINITY
8.9
27
R
LOWER KEECHI CREEK
207.7
19.2
D
R
29
BEDIAS CREEK
R
189.0
183.3
10.5
D
R
30
HARMONS CREEK
MUSTANG CREEK
31
23.7
GAIL CREEK
32
25.3
R D
10.0
R
1.2
7.7
33
CANEY CREEK
D
WHITE ROCK CREEK
169.9
RIVER
34
129.2
R D
LONG TOM CREEK
35
21.4
R
11.0
118.9
R
100.0
R D
40.0
36
3.9
D
TRINITY BAY

LEGEND

△ RESERVOIR

▨ REACH REQUIRING REGULATION FLOWS TO MAINTAIN ORGANIC QUALITY

339.6 RIVER MILEAGE

R→ RETURN FLOW

D→ DIVERSION

WATER RESOURCES STUDY
TRINITY RIVER BASIN–TEXAS

SCHEMATIC DIAGRAM FOR ORGANIC POLLUTION STUDY

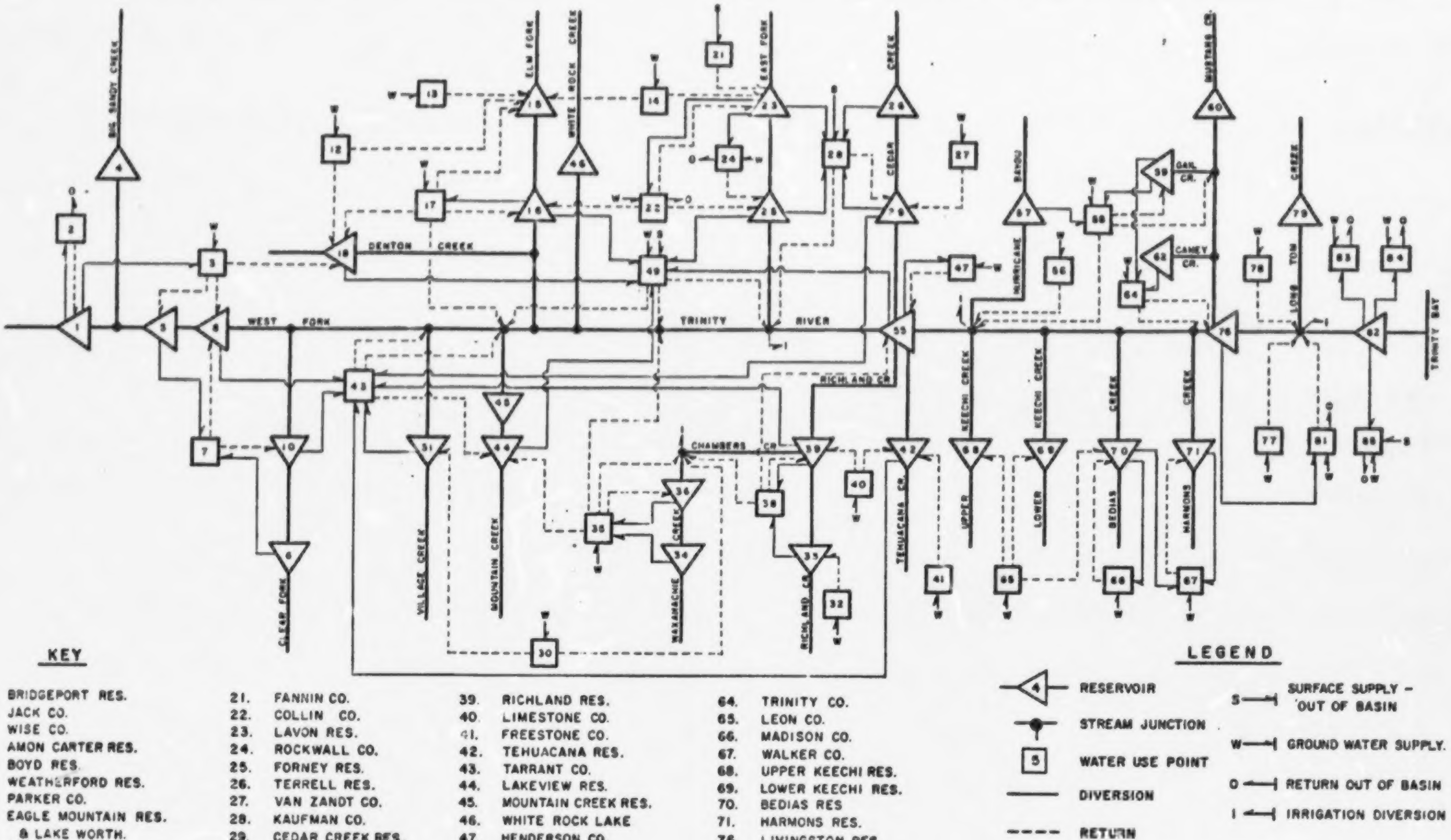
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE C-1

To expedite these calculations, a program was developed for the Bendix G-15 computer which made these calculations for the entire basin simultaneously, then automatically calculated the total dissolved solids at all points in the system at specified time intervals for the critical period through the year 1956. It was then possible to determine the total annual, maximum and minimum monthly, and average annual amounts of water required to maintain total dissolved solid concentration under 1,000 mg/l. The mathematical model of the Trinity River basin that was constructed for use in the computer program is shown in Figure C-2.

Determination of Regulation Water Requirements

A comparison of the mineral and organic studies was then made, from which it was possible to determine the total amount of water required to maintain stream quality. Benefits of storage for water quality control were determined based on these amounts.



BIG SANDY CREEK
ELM FORK
WHITE ROCK CREEK
EAST FORK
CEDAR
CREEK
BAYOU
HURRICANE
MUSTANG CR.
GAIL CR.
CANEY CR.
LONG TOM
CREEK
DENTON CREEK
WEST FORK
TRINITY RIVER
TRINITY BAY
RICHLAND CR.
CHAMBERS CR.
CLEAR FORK
VILLAGE CREEK
MOUNTAIN CREEK
WAXAHACHIE CREEK
RICHLAND CR.
TEHUACANA CR.
UPPER KEECHI CREEK
LOWER KEECHI CREEK
BEDIAS CREEK
HARMONS CREEK
LEGEND
RESERVOIR
STREAM JUNCTION
WATER USE POINT
DIVERSION
RETURN
S SURFACE SUPPLY - OUT OF BASIN
W GROUND WATER SUPPLY.
O RETURN OUT OF BASIN
I IRRIGATION DIVERSION

KEY

1.	BRIDGEPORT RES.
2.	JACK CO.
3.	WISE CO.
4.	AMON CARTER RES.
5.	BOYD RES.
6.	WEATHERFORD RES.
7.	PARKER CO.
8.	EAGLE MOUNTAIN RES. & LAKE WORTH.
10.	BENBROOK RES.
12.	MONTAGUE CO.
13.	COOKE CO.
14.	GRAYSON CO.
15.	AUBREY RES.
16.	GARZA-LITTLE ELM RES.
17.	DENTON CO.
18.	ROANOKE RES. & GRAPEVINE RES.
21.	FANNIN CO.
22.	COLLIN CO.
23.	LAVON RES.
24.	ROCKWALL CO.
25.	FORNEY RES.
26.	TERRELL RES.
27.	VAN ZANDT CO.
28.	KAUFMAN CO.
29.	CEDAR CREEK RES.
30.	JOHNSON CO.
31.	LAKE ARLINGTON
32.	HILL CO.
33.	NAVARRO MILLS RES.
34	WAXAHACHIE RES.
35.	ELLIS CO.
36.	BARDWELL RES.
38.	NAVARRO CO.
39.	RICHLAND RES.
40.	LIMESTONE CO.
41.	FREESTONE CO.
42.	TEHUACANA RES.
43.	TARRANT CO.
44.	LAKEVIEW RES.
45.	MOUNTAIN CREEK RES.
46.	WHITE ROCK LAKE
47.	HENDERSON CO.
49.	DALLAS CO.
55.	TENNESSEE COLONY RES.
56.	ANDERSON CO.
57.	HURRICANE RES.
58.	HOUSTON CO.
59.	GAIL RES.
60.	MUSTANG RES.
62.	CANEY RES.
64.	TRINITY CO.
65.	LEON CO.
66.	MADISON CO.
67.	WALKER CO.
68.	UPPER KEECHI RES.
69.	LOWER KEECHI RES.
70.	BEDIAS RES
71.	HARMONS RES.
76.	LIVINGSTON RES.
77.	SAN JACINTO CO.
78.	POLK CO.
79.	LONG KING RES.
81.	LIBERTY CO.
82.	WALLISVILLE RES.
83.	CHAMBERS CO.
84.	GALVESTON CO.
85.	HARRIS CO.

WATER RESOURCES STUDY
TRINITY RIVER BASIN—TEXAS
MATHEMATICAL MODEL FOR
INORGANIC POLLUTION STUDY
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE C-2

APPENDIX D

CALCULATIONS FOR BENEFITS OF STORAGE

The alternatives to the Federal projects were determined to be single-purpose reservoirs at the project site. The Corps of Engineers furnished the initial and operations and maintenance costs for these projects as shown in Table D-1.

Table D-1

Cost of Alternative Single-Purpose Projects

Project	Yield (mgd)	Initial Cost ($)	Annual O. & M. Cost ($)
Lakeview Reservoir	28.4	20,138,000	85,500
Aubrey Reservoir	65.3	24,240,000	96,000
Tennessee Colony Reservoir	290.8	41,710,000	142,000
Roanoke Reservoir	19.4	15,505,000	51,000

The total benefits of storage were then calculated as follows:

Lakeview Reservoir:

Amortization period: 100 years @ 4% per annum
Annual capital cost = (20,138,000) (0.040808) = $ 821,800
Annual operations and maintenance cost = 85,500
Total annual benefit = $ 907,300

$$\text{Or: } \frac{\$907,300/\text{year } (100¢/\$)\ (1,000 \text{ gal.})}{(28.4 \text{ mgd})\ (365 \text{ days/year})} = 8.8¢/1,000 \text{ gal.}$$

Aubrey Reservoir:

Amortization period: 100 years @ 4% per annum
Annual capital cost = (24,240,000) (0.040808) = $ 989,200
Annual operations and maintenance cost = 96,000
Total annual benefit = $1,085,200

$$\text{Or: } \frac{\$1,085,200/\text{year } (100¢/\$)\ (1,000 \text{ gal.})}{(65.3 \text{ mgd})\ (365 \text{ days/year})} = 4.6¢/1,000 \text{ gal.}$$

Roanoke Reservoir:

Amortization period: 100 years @ 4% per annum
Annual capital cost = (15,505,000) (0.040808) = $ 632,700
Annual operations and maintenance cost = 51,000
Total annual benefit in the year 2000 = $ 683,700
1970 present worth of annual benefit = $ 210,800

$$\text{Or: } \frac{\$210,800/\text{year } (100¢/\$)\ (1,000 \text{ gal.})}{(19.4 \text{ mgd})\ (365 \text{ days/year})} = 3.0¢/1,000 \text{ gal.}$$

Tennessee Colony Reservoir:

Amortization period: 100 years @ 4% per annum
Annual capital cost = (41,710,000) (0.040808) = \$1,702,100
Annual operations and maintenance cost = 142,000
Total annual benefit = \$1,844,100

Or: $\dfrac{\$1{,}844{,}100/\text{year}\ (100¢/\$)\ (1{,}000\ \text{gal.})}{(290.8\ \text{mgd})\ (365\ \text{days/year})} = 1.7¢/1{,}000\ \text{gal.}$

The distribution of benefits between municipal and industrial and quality control purposes were calculated as follows:

Aubrey Reservoir: Total annual benefits in 1970 -- \$1,085,200

From Yield-Demand Curve:

	Demand (%)			% of Areal Yield Used
Year	M & I	Water Quality	Total	
1970	0	100	100	61
1980	6	94	100	71
1985	9	91	100	100
1990	100	0	100	100

Tennessee Colony Reservoir: Total annual benefits in 1970--\$1,844,100

For the purpose of water quality, the cost of transporting the water to the point of need must be added since this is a governmental function. This cost was obtained from the Corps of Engineers based on an 84-inch pipeline costing \$56,644,000 and power, operation, maintenance, and replacement costs of \$1,434,000 per annum. This cost plus the portion of the cost of storage for water quality control is \$4,329,200, and the cost for M & I is then \$1,260,400. The benefit distribution between quality and M & I water is as follows:

Year	M & I	Water Quality
1970	1,260,400	4,329,200
1980	1,260,400	4,329,200
1990	1,260,400	4,329,200
2000	1,260,400	4,329,200
2010	1,260,400	4,329,200
2020	1,260,400	4,329,200
2030	3,657,800	1,931,800
2040	5,589,600	-0-

APPENDIX E

SUPPLEMENTAL TABLES

The tables that follow each have significant bearing on the findings of this report. They have been placed together in Appendix form in the interest of continuity in the text and for the convenience of the reader.

The identifying number on each entry in this Appendix corresponds to the number of the report section to which it refers.

Table III-1 17/

Characteristics of the Subareas

Sub-area No.	Counties	Principal Cities	1960 Population	Population Class	Economy	Topography	Altitude (feet)	Mean Annual Temperature (°F)	Growing Season (days)	Avg. Rainfall (inches)
1	Archer, Clay, Jack, Palo Pinto, Young	Holliday, Henrietta, Jacksboro, Mineral Wells, Graham	59,649	Non-Metropolitan	Farm - Livestock and oil	Rolling plains to hilly	800-1,450	64	220	27.6
2	Montague, Parker, Wise	Bowie, Weatherford, Decatur	54,785	Non-Metropolitan	Farm - Livestock	Rolling plains to hilly	700-1,400	63	228	30.6
3	Cooke, Grayson	Gainesville, Sherman	95,603	Non-Metropolitan	Industrial, Agricultural, Oil	Rolling plains	500-1,100	65	235	36.7
4	Fannin, Hunt, Kaufman, Rockwall	Bonham, Greenville, Terrell, Rockwall	99,088	Non-Metropolitan	Agricultural, Industrial	Rolling plains	300-700	64	233	40.1
5	Anderson, Delta, Henderson, Hopkins, Houston, Rains, Van Zandt	Palestine, Cooper, Athens, Sulphur Springs, Crockett, Emory, Canton	115,862	Non-Metropolitan	Agricultural, Forest, Industrial, Oil	Rolling to hilly	200-800	66	243	40.2
6	Freestone, Hill, Leon, Limestone, Madison, Navarro	Fairfield, Hillsboro, Centerville, Mexia, Madisonville, Corsicana	107,711	Non-Metropolitan	Agricultural, Livestock, Industrial	Level to rolling	200-900	66	243	38.0
7	Hardin, Montgomery, Polk, San Jacinto, Trinity, Walker	Kountze, Conroe, Livingston, Coldspring, Groveton, Huntsville	100,496	Non-Metropolitan	Agricultural, Livestock, Forest, Oil	Coastal plain to rolling	30-450	67	261	47.5
8 a/	Johnson, Tarrant	Cleburne, Fort Worth	573,215	Metropolitan	Industrial, Commercial, Some Agricultural	Rolling prairie	500-1,000	65	238	33.3
9 b/	Collin, Dallas, Denton, Ellis	McKinney, Dallas, Denton, Waxahachie	1,083,601	Metropolitan	Industrial-Commercial, Some Agricultural	Rolling prairie	300-900	65	238	35.7
10 c/	Brazoria, Chambers, Fort Bend, Galveston, Harris, Jefferson, Liberty	Freeport, Anahuac, Rosenberg, Galveston, Houston, Beaumont, Liberty	1,787,886	Metropolitan	Industrial Commercial, Oil, Chemical, Forest, Agricultural, Livestock	Coastal Plains	0-300	68	288	46.3

a/ Comprises the Fort Worth SMSA.

b/ Comprises the Dallas SMSA.

c/ Includes the Houston, Beaumont, Port Arthur, and Galveston-Texas City SMSA's.

Table IV-1 11,12/

Existing Major Reservoirs

Sub-area Loca-tion	Reservoir	River Basin	Present Total Capacity (Ac. Ft.)	Date Com-pleted	Ownership	Use
1	Lake Wichita	Red	14,030	1901	City of Wichita Falls	M&I[a]
	Lake Kickapoo	Red	105,000	1946	City of Wichita Falls	M&I
	Lake Eddleman	Brazos	5,917	1929	City of Graham	M&I
	Salt Creek Lake	Brazos	39,000	1959	City of Graham	M&I
	Possum Kingdom	Brazos	733,800	1941	Brazos River Authority	HP
2	Lake Mineral Wells	Brazos	9,030	1943	City of Mineral Wells	M&I
	Lake Weatherford	Trinity	19,470	1956	City of Weatherford	M&I
	Lake Bridgeport	Trinity	270,300	1932	Tarrant Co. WCID No.1	M&I
	Amon Carter Res.	Trinity	20,000	1956	City of Bowie	M&I
3	Lake Texoma	Red	5,530,000	1944	U.S. Corps of Engineers	MP
4	Lake Coffee Mills	Red	8,000	1940	U.S. Forest Service	R
	Iron Bridge Res.	Sabine	926,000	1961	Sabine River Authority	M&I
	Lake Terrell	Trinity	8,300	1956	City of Terrell	M&I
5	Lake Trinidad	Trinity	6,240	1925	Texas Power and Light Co.	TP
	Cedar Creek Res.	Trinity	608,000	(b)	Tarrant Co. WCID No. 1	M&I
	Blackburn Crossing Res.	Neches	30,000	(b)	Upper Neches River Mun. Water Auth.	M&I
6	Lake Whitney	Brazos	2,017,500	1951	U. S. Corps of Engineers	MP
	Navarro Mills Res.	Trinity	212,200	(b)	U. S. Corps of Engineers	MP
	Bistone Res.	Brazos	6,500	(b)	Bistone Municipal Water Supply Dist.	M&I
	Lake Halbert	Trinity	6,250	1924	City of Corsicana	M&I
7	Livingston Res.	Trinity	1,750,000	(b)	Trinity River Authority	M&I

Table IV-1 (Continued)

Existing Major Reservoirs

Sub-area Loca-tion	Reservoir	River Basin	Present Total Capacity (Ac. Ft.)	Date Com-pleted	Ownership	Use
8	Lake Worth	Trinity	47,177	1913	City of Fort Worth	M&I
	Benbrook Res.	Trinity	258,600	1952	U. S. Corps of Engineers	MP
	Lake Arlington	Trinity	45,710	1957	City of Arlington	M&I
	Eagle Mountain Res.	Trinity	182,000	1934	Tarrant Co. WCID No. 1	M&I
	Marine Creek Dam	Trinity	15,366	1957	Tarrant Co. WCID No. 1	R&FC
	Garza-Little Elm Res.	Trinity	1,016,200	1954	U. S. Corps of Engineers	MP
9	Lavon Res.	Trinity	423,400	1953	U. S. Corps of Engineers	MP
	Forney Res.	Trinity	490,000	(b)	City of Dallas	M&I
	Mountain Creek Lake	Trinity	27,100	1936	Dallas Power and Light Co.	TP
	North Lake	Trinity	16,000	1957	Dallas Power and Light Co.	TP
	White Rock Lake	Trinity	12,300	1911	City of Dallas	M&I[a]
	Waxahachie Res.	Trinity	13,500	1955	Ellis Co. WCID No. 1	M&I
	Grapevine Res.	Trinity	435,500	1952	U. S. Corps of Engineers	MP
	Bardwell Res.	Trinity	117,800	(c)	U. S. Corps of Engineers	MP
10	Lake Anahuac	Coastal	35,300	1954	Chambers-Liberty Co. Nav. Dist.	Ir
	Sheldon Res.	San Jacinto	6,950	1947	Texas Game and Fish Commission	X
	Highlands Res.	San Jacinto	5,575	1943	San Jacinto River Authority	M&I
	Barker Res.	San Jacinto	204,800	1945	U. S. Corps of Engineers	FC
	Addicks Res.	San Jacinto	204,500	1948	U. S. Corps of Engineers	FC
	Lake Houston	San Jacinto	160,000	1954	City of Houston	M&I

Use Code: M&I - Municipal and Industrial; HP - Hydropower; FC - Flood Control; MP - Multiple Purpose; TP - Thermal Power; R- Recreation; Ir - Irrigation; X - Fish and Game.

Notes: a/ Used only in case of emergency
b/ Under construction
c/ Authorized

Table IV-2 12/

Pertinent Data - Existing and Authorized Reservoirs Trinity River Basin

Reservoir	Stream	River Mile	Drainage Area (Sq. Mi)	Date of Completion	2020 Yield (mgd)	Storage in Millions of Gallons				
						Flood Control	Conservation	Sedimentation	Navigation	Total
Existing Corps of Engineers										
Benbrook	Clear Fork Trinity River	15.0	433	1952	6.5	55,509	23,624	5,132	--	84,265
Grapevine	Denton Creek	11.7	694	1952	42.0	15,413	121,281	5,214	--	141,908
Garza-Little Elm	Elm Fork Trinity River	30.0	1,658	1954	77.6	108,052	209,815	13,262	--	331,129
Lavon	East Fork Trinity River	55.9	777	1953	35.5	89,804	32,585	15,576	--	137,965
Navarro Mills	Richland Creek	63.9	316	(2)	18.1	46,662	17,335	5,148	--	69,145
Authorized Corps of Engineers										
Bardwell	Waxahachie Creek	6.0	171	--	5.5	25,938	9,613	2,835	--	38,386
Existing Local Interest										
Bridgeport	West Fork Trinity River	626.2	1,114	1932	50.4	--	75,988	11,763	--	87,751
Amon Carter	Big Sandy Creek	27.7	103	1956	0	--	--	--	--	6,517
Eagle Mountain	West Fork Trinity River	583.3	1,974	1934	4.5(b)	--	46,759	12,513	--	59,272
Lake Worth	West Fork Trinity River	572.0	2,069	1913	4.5(b)	--	10,297	684	--	10,981
Weatherford	Clear Fork Trinity River	38.7	106	1956	0.6	--	4,269	2,085	--	6,354
Arlington	Village Creek	8.0	136	1957	5.8	--	11,600	3,389	--	14,989
Mountain Creek	Mountain Creek	4.1	289	1936	0	--	--	--	--	7,886
White Rock	White Rock Creek	12.0	99	1911	0	--	--	--	--	--
Lake Terrell	Muddy Cedar Creek		13	1956	0.6	--	2,314	--	--	2,314
Cedar Creek	Cedar Creek	11.1	1,013	(a)	173.2	--	198,117	13,718	--	211,835
Waxahachie	S. Prong Waxahachie Creek		31	1955	1.9	--	3,715	--	--	3,715
Lake Anahuac	Trinity River		122	1953	13.4	--	11,405	--	--	11,405
Forney	East Fork Trinity River	31.8	1,074	(a)	58.8	--	151,846	7,820	--	159,666
Livingston	Trinity River	129.2	12,606	(a)	571.3	--	553,424	16,814	--	570,238

Note: (a) Under Construction
(b) With Boyd Reservoir in the system

Table IV-3 12/

Pertinent Data - Proposed Reservoirs
Trinity River Basin

Reservoir	Stream	River Mile	Drainage Area (Sq. Mile)	Yield (mgd)	Storage in millions of gallons Flood Control	Conser-vation	Sedimen-tation	Total
Corps of Engineers								
Lakeview	Mountain Creek	7.2	272	30.4	48,617	103,229	7,397	159,243
Tennessee Colony	Trinity River	339.6	12,687	290.8	818,991	247,125	30,956	1,099,072
Wallisville	Trinity River	3.9	17,760	146.0	NA	12,000	NA	NA
Lavon (Enlargement)	East Fork Trinity River	55.9	777	42.7	--	85,470	--	85,470
Aubrey	Elm Fork Trinity River	60.0	682	75.0	79,996	195,510	12,317	287,823
Roanoke	Denton Creek	31.4	604	0	72,436	--	8,537	80,973
Local Interests								
Richland Creek	Richland Creek	5.2	1,978	169,6	--	325,850	14,728	340,578
Tehuacana Creek	Tehuacana Creek	11.2	356	56.6	--	92,053	4,171	96,224
Upper Keechi	Upper Keechi Creek	11.0	486	54.3	--	40,731	3,096	43,827
Lower Keechi	Lower Keechi Creek	8.9	162	25.2	--	55,395	978	56,373
Bedias	Bedias Creek	19.2	327	94.4	--	117,306	5,442	122,748
Harmons	Harmons Creek	10.5	47	16.8	--	25,416	358	25,774
Hurricane	Hurricane Creek	7.0	91	17.5	--	48,878	619	49,497
Gail	Gail Creek	25.3	91	31.0	--	54,743	619	55,362
Mustang	Mustang Creek	23.7	84	25.2	--	50,833	554	51,387
Caney	Caney Creek	7.7	74	25.2	--	43,664	521	44,185
Long King	Long King Creek	21.4	100	34.9	--	59,956	717	60,673
Boyd	West Fork Trinity River	604.7	1,707	24.6	--	129,037	12,773	141,810
Capers Ridge	Trinity River	63.0	NA	97.0	--	NA	NA	NA

Table IV-4 3/

1958 Ground Water Use by Aquifer

Aquifer	No. Wells	Total Amount Withdrawn (Mil. gal.)	Average Daily Use (Mil. gal.)
Alluvium	40	2,041.58	5.591
Beaumont Clay	117	10,456.02	28.791
Beaumont Clay-Alluvium	21	1,393.42	3.837
Canyon Group	3	8.76	0.024
Carrizo Sand	9	129.48	1.134
Catahoula Tuff-Oakville Sandstone-Lagarto Clay	24	1,109.65	3.042
Cisco Group	48	103.48	0.284
Glen Rose Limestone	1	1.84	0.005
Goliad Sand-Lissie Sand	6	75.34	0.207
Goliad Sand-Lissie Sand-Beaumont Clay-Alluvium	1	131.40	0.360
Goliad Sand-Willis Sand-Lissie Sand	111	21,132.70	61.545
Goliad Sand-Willis Sand-Lissie Sand-Beaumont Clay	201	43,647.71	141.477
Jackson Group	7	215.50	0.590
Lagarto Clay	2	122.91	0.337
Lissie Sand	154	12,562.94	34.419
Lissie Sand-Beaumont Clay	8	300.50	0.823
Nacatoch Sand	14	509.18	1.334
Ogallala Formation	1	0.002	0.00005
Paluxy Formation	79	725.04	2.070
Queen City Sand	3	74.82	0.205
Queen City Sand-Wilcox Group	4	24.24	0.067
Seymour Formation	1	4.54	0.013
Sparta Sand	3	361.35	0.990
Strawn Group	1	0.12	0.0003
Trinity Sand	136	4,968.82	15.295
Trinity Sand-Paluxy Formation	69	2,197.29	6.068
Trinity Sand-Woodbine Formation	36	1,061.48	3.616
Trinity Sand-Woodbine Formation-Paluxy Formation	117	5,159.81	14.858
Wilcox Group	28	1,263.48	3.476
Willis Sand-Lissie Sand	--	5.48	0.015
Woodbine Formation	103	2,206.55	6.652
Woodbine Formation-Alluvium	1	20.00	0.072
Woodbine Formation-Paluxy Formation	12	196.75	0.579
Yegua Formation	6	146.61	0.402
Catahoula-Oakville-Lagarto-Golliad-Willis-Lissie	17	457.82	1.264
Unknown	1	3.10	0.007
TOTAL	1,385	112,819.71	339.449

Table IV-5 15/

Ground Water Potential of the Study Area

Sub-area	County	Aquifer	Estimated 2020 Ground Water Yield - mgd	Remarks
1	Archer	Ci	0.3	For nonmunicipal needs
	Clay	Ci	0.4	For nonmunicipal needs
	Jack	Can, Tri	0.4	For nonmunicipal needs
	Palo Pinto	St, Can	1.0	For nonmunicipal needs
	Young	Ci	0.5	
Subtotal			2.6	
2	Montague	Ci, W, A	15.0	
	Parker	S, Tri	34.0	
	Wise	Tri, S, Can	30.0	
Subtotal			79.0	
3	Cooke	Tri, Wo	30.0	
	Grayson	Tri, Wo	15.0	
Subtotal			45.0	
4	Fannin	Wo, A	5.0	
	Hunt	Wo, N	0.5	For nonmunicipal needs
	Kaufman	A	1.1	For nonmunicipal needs
	Rockwall	Wo, A	1.0	
Subtotal			7.6	
5	Anderson	Car-Wx, QC	150.0	
	Delta	A	0.3	For nonmunicipal needs
	Henderson	Car-Wx, QC	95.0	
	Hopkins	Wx	10.0	
	Houston	Car-Wx, QC, Sp.	45.0	
	Rains	Wx	9.0	
	Van Zandt	Car-Wx, QC	25.0	
Subtotal			234.3	
6	Freestone	Car-Wx, A	100.0	
	Hill	Tri, Wo	15.0	
	Leon	Car-Wx, QC, Sp.	150.0	
	Limestone	Wx	30.0	
	Madison	Und.	3.0	
	Navarro	A	0.9	For nonmunicipal needs
Subtotal			298.9	
7	Hardin	Col-GWL-B	220.0	
	Montgomery	Col-GWL	290.0	
	Polk	Col-GWL	200.0	
	San Jacinto	Col-GWL	150.0	
	Trinity	A, Und.	5.5	
	Walker	GWL	60.0	
Subtotal			925.5	

Table IV-5 (Continued)

Ground Water Potential of the Study Area

Sub-area	County	Aquifer	Estimated 2020 Ground Water Yield - mgd	Remarks
8	Johnson	Tri, Wo	20.0	
	Tarrant	Tri, Wo	60.0	
Subtotal			80.0	
9	Collin	Tri, Wo	10.0	
	Dallas	Tri, Wo	30.0	
	Denton	Tri, Wo	60.0	
	Ellis	Wo	10.0	
Subtotal			110.0	
10	Brazoria	Col, GWL, B	140.0	
	Chambers	B	20.0	
	Galveston	B	37.0	
	Fort Bend	Col, GWL, B	140.0	
	Harris	Col, GWL, B	500.0	
	Jefferson	B	40.0	
	Liberty	Col, GWL, B	210.0	
Subtotal			1,087.0	
Total			2,869.9	

Aquifer Code:

A	Alluvium
B	Beaumont Clay
BA	Beaumont Clay-Alluvium
Can	Canyon Group
Car	Carrizo Sand
Col	Catahoula Tuff-Oakville Sandstone-Lagarto Clay
Ci	Cisco Group
GWL	Goliad Sand-Willis Sand-Lissie Sand
N	Nacatoch Sand
QC	Queen City Sand
S	Strawn Group
Tri	Trinity Sand
Und.	Undetermined
W	Wichata
Wo	Woodbine Formation
Wx	Wilcox Group
Sp	Sparta Sand
Car-Wx	Carrizo Sand-Wilcox Group

Table V-4

Agricultural Statistics for the Study Area 1944-1959

Year	Number Of Farms (Thousands)	Cropland Harvested (1,000 Acres)	*Value of Crops Sold (Million $)	*Value of Livestock & Livestock Products Sold (Million $)
Total Study Area				
1944	115.6	5,280.6	146.3	114.7
1949	95.2	4,960.7	183.6	131.1
1954	93.5	4,436.1	162.0	116.8
1959	62.2	3,509.3	N.A. a/	N.A.
Subarea 1				
1944	5.5	395.9	4.5	14.0
1949	4.8	380.4	5.8	19.8
1954	4.1	289.0	4.7	13.6
1959	3.3	200.4	N.A.	N.A.
Subarea 2				
1944	6.3	249.5	3.4	9.9
1949	5.8	202.3	3.8	12.6
1954	5.4	161.8	2.1	13.9
1959	4.2	119.3	N.A.	N.A.
Subarea 3				
1944	6.4	425.4	9.9	7.5
1949	5.6	376.3	8.2	7.7
1954	4.5	326.4	7.2	7.1
1959	3.8	295.4	N.A.	N.A.
Subarea 4				
1944	12.9	750.6	19.7	7.9
1949	10.2	693.1	25.1	8.7
1954	8.2	595.2	16.7	7.2
1959	6.4	473.2	N.A.	N.A.
Subarea 5				
1944	20.7	600.2	17.3	12.4
1949	17.4	550.1	21.6	12.5
1954	14.4	452.2	12.8	13.6
1959	10.5	285.6	N.A.	N.A.
Subarea 6				
1944	15.7	853.9	20.5	10.8
1949	14.3	850.4	32.8	12.7
1954	11.9	759.2	20.3	11.7
1959	9.0	551.8	N.A.	N.A.

Table V-4 (Continued)

Agricultural Statistics for the Study Area 1944-1959

Year	Number Of Farms (Thousands)	Cropland Harvested (1,000 Acres)	*Value of Crops Sold (Million $)	*Value of Livestock & Livestock Products Sold (Million $)
Subarea 7				
1944	8.4	92.7	1.6	3.1
1949	6.8	80.2	2.8	4.3
1954	7.0	80.9	2.6	4.5
1959	4.8	56.4	N.A.	N.A.
Subarea 8				
1944	6.9	310.8	8.2	12.0
1949	6.0	256.3	7.1	15.8
1954	5.5	224.1	4.3	12.6
1959	3.7	194.7	N.A.	N.A.
Subarea 9				
1944	15.8	1,135.0	31.8	17.5
1949	13.4	1,007.3	39.3	16.4
1954	20.9	924.2	28.2	14.5
1959	7.9	840.7	N.A.	N.A.
Subarea 10				
1944	17.0	466.6	29.4	19.6
1949	10.9	564.3	37.1	20.6
1954	11.6	623.1	63.1	18.1
1959	8.6	491.8	N.A.	N.A.

*1958 Const. $.

a/ Not available.

Table V-6

Number and Percentage of the Labor Force in the Subareas of the Trinity River Basin Study Area by Industrial Categories - 1940, 1950, and 1960

	Subarea 1						Subarea 2						Subarea		
	1940		1950		1960		1940		1950		1960		1940		1950
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number
Agriculture	6,999	28.9	4,694	21.6	3,203	14.4	8,656	41.3	5,396	27.3	4,163	20.8	9,410	26.3	5,979
Forestry and Fisheries	8	--	30	.2	22	.1	38	.2	15	.1	21	.1	3	--	9
Mining	2,023	8.4	2,759	12.7	2,164	9.8	593	2.9	1,169	5.9	1,147	5.7	445	1.3	777
Manufacturing	906	3.7	1,570	7.2	1,501	6.8	803	3.8	2,417	12.2	1,777	8.9	2,885	8.1	4,462
Resource-Oriented	722	3.0	740	3.4	972	4.4	645	3.0	966	4.9	1,012	5.1	1,711	4.8	2,303
Furniture, Lumber & Wood Products	181	.7	200	.9	76	.4	45	.2	38	.2	204	1.0	166	.5	323
Primary Metals	9	--	36	.2	0	--	26	.1	17	.1	8	--	32	.1	52
Food and Kindred Products	212	.9	257	1.2	242	1.1	227	1.1	292	1.5	232	1.2	1,120	3.1	1,454
Chemical and Allied Products	53	.2	18	.1	71	.3	9	--	45	.2	7	--	289	.8	171
Stone, Clay, & Glass Products	112	.5	115	.5	381	1.7	157	.7	300	1.5	326	1.7	19	.1	140
Other Nondurable Goods	155	.6	114	.5	202	.9	181	.9	274	1.4	235	1.2	85	.2	163
Nonresource-Oriented	184	.7	830	3.8	529	2.4	158	.8	1,451	7.3	765	3.8	1,174	3.3	2,159
Fabricated Metals, etc.*	72	.3	598	2.8	391	1.8	45	.2	1,149	5.8	567	2.8	223	.6	475
Apparel and Textiles	5	--	98	.4	55	.2	16	.1	188	.9	130	.7	686	1.9	1,352
Printing, Publishing, NEC	107	.4	134	.6	83	.4	97	.5	114	.6	68	.3	265	.8	332
Basic Industries	9,936	41.0	9,053	41.7	6,890	31.1	10,090	48.2	8,997	45.5	7,108	35.5	12.743	35.7	11,227
Service Industries	9,932	41.0	11,947	55.0	14,182	63.9	7,498	35.8	10,259	51.8	11,910	59.5	16,214	45.4	21,074
Unemployed	4,344	18.0	718	3.3	1,109	5.0	3,353	16.0	539	2.7	1,000	5.0	6,766	18.9	1,337
Labor Force	24,212	100.0	21,718	100.0	22,181	100.0	20,941	100.0	19,795	100.0	20,018	100.0	35,723	100.0	33,638
Population	67,789		58,431		59,649		59,998		54,739		54,785		94,408		92,613

	Subarea 6						Subarea 7						Subarea		
	1940		1950		1960		1940		1950		1960		1940		1950
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number
Agriculture	29,839	48.6	16,107	35.8	10,063	27.2	11,757	33.4	5,090	16.2	4,030	12.2	8,155	7.6	5,576
Forestry and Fisheries	8	--	33	.1	40	.1	66	.2	147	.5	109	.3	23	--	19
Mining	866	1.4	633	1.4	421	1.1	1,168	3.3	1,804	5.8	1,191	3.6	870	.8	1,551
Manufacturing	2,280	3.7	3,575	8.0	3,851	10.4	6,015	17.1	7,774	24.8	4,933	14.9	14,426	13.4	38,474
Resource-Oriented	964	1.6	1,549	3.5	1,335	3.6	5,849	16.6	7,374	23.5	4,429	13.4	9,138	8.5	14,138
Furniture, Lumber & Wood Products	234	.4	329	.7	332	.9	5,428	15.4	6,621	21.1	3,534	10.7	831	.8	1,387
Primary Metals	91	.1	141	.3	196	.5	4	--	18	.1	0	--	150	.1	916
Food and Kindred Products	338	.6	469	1.1	455	1.2	98	.3	125	.4	231	.7	5,845	5.4	8,018
Chemical and Allied Products	116	.2	163	.4	3	--	28	.1	118	.4	240	.7	454	.4	800
Stone, Clay, & Glass Products	32	.1	300	.7	307	.9	35	.1	40	.1	40	.1	268	.3	800
Other Nondurable Goods	153	.2	147	.3	42	.1	256	.7	452	1.4	384	1.2	1,590	1.5	2,217
Nonresource-Oriented	1,316	2.1	2,026	4.5	2,516	6.8	166	.5	400	1.3	504	1.5	5,288	4.9	24,336
Fabricated Metals, etc.*	149	.2	178	.4	103	.3	62	.2	273	.9	302	.9	1,936	1.8	18,984
Apparel and Textiles	975	1.6	1,647	3.7	2,230	6.0	9	--	12	--	53	.2	1,417	1.3	2,764
Printing, Publishing, NEC	192	.3	201	.4	183	.5	95	.3	115	.4	149	.4	1,935	1.8	2,588
Basic Industries	33,013	53.7	20,348	45.3	14,375	38.8	19,006	54.0	14,815	47.3	10,263	31.0	23,474	21.8	45,620
Service Industries	19,870	32.4	22,808	50.7	20,809	56.2	11,858	33.7	15,547	49.7	21,217	64.0	66,693	61.9	117,318
Unemployed	8,520	13.9	1,802	4.0	1,852	5.0	4,328	12.3	942	3.0	1,656	5.0	17,580	16.3	4,636
Labor Force	61,403	100.0	44,958	100.0	37,036	100.0	35,190	100.0	31,304	100.0	33,136	100.0	107,747	100.0	167,574
Population	174,344		132,165		107,711		102,194		97,608		100,496		255,905		392,643

*Includes Fabricated Metals, Machinery, Electrical Equipment, Motor Vehicles, Transportation Equipment, and Other Durable Goods.

ble V-6

ntage of the Labor Force
Trinity River Basin Study Area
ries - 1940, 1950, and 1960

		Subarea 3						Subarea 4						Subarea 5					
1960		1940		1950		1960		1940		1950		1960		1940		1950		1960	
	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
163	20.8	9,410	26.3	5,979	17.8	4,105	11.7	21,310	45.5	12,982	33.1	8,109	23.3	32,326	51.6	17,155	37.7	11,254	29.0
21	.1	3	--	9	--	9	--	5	--	6	--	21	.1	31	--	69	.1	30	.1
147	5.7	445	1.3	777	2.3	1,056	3.0	71	.2	46	.1	33	.1	1,386	2.2	1,082	2.4	978	2.5
777	8.9	2,885	8.1	4,462	13.3	6,737	19.2	1,886	4.0	3,480	8.9	6,238	17.9	2,489	4.0	3,416	7.5	3,534	9.1
012	5.1	1,711	4.8	2,303	6.9	3,576	10.2	853	1.8	1,376	3.5	1,598	4.6	2,182	3.5	2,826	6.2	2,196	5.7
204	1.0	166	.5	323	1.0	251	.7	82	.2	119	.3	254	.7	1,194	1.9	1,282	2.8	395	1.0
8	--	32	.1	52	.2	82	.2	14	--	29	.1	429	1.2	0	--	19	--	2	--
332	1.2	1,120	3.1	1,454	4.3	1,740	5.0	534	1.2	683	1.7	686	2.0	393	.6	462	1.0	616	1.6
7	--	289	.8	171	.5	50	.1	194	.4	193	.5	87	.2	286	.5	361	.8	219	.6
326	1.7	19	.1	140	.4	285	.8	9	--	20	.1	20	.1	182	.3	450	1.0	915	2.4
235	1.2	85	.2	163	.5	1,168	3.3	20	--	332	.8	122	.4	127	.2	252	.6	49	.1
765	3.8	1,174	3.3	2,159	6.4	3,161	9.0	1,033	2.2	2,104	5.4	4,640	13.3	307	.5	590	1.3	1,338	3.4
067	2.8	223	.6	475	1.4	1,031	2.9	165	.4	582	1.5	2,637	7.6	80	.1	242	.5	576	1.5
130	.7	686	1.9	1,352	4.0	1,834	5.2	627	1.3	1,175	3.0	1,681	4.8	34	.1	155	.4	628	1.6
68	.3	265	.8	332	1.0	296	.9	241	.5	347	.9	322	.9	193	.3	193	.4	134	.3
108	35.5	12,743	35.7	11,227	33.4	11,907	33.9	23,272	49.7	16,514	42.1	14,401	41.4	36,232	57.8	21,722	47.7	15,796	40.7
910	59.5	16,214	45.4	21,074	62.6	21,433	61.2	16,236	34.6	21,131	53.8	18,687	53.7	19,102	30.5	22,703	49.9	21,115	54.3
000	5.0	6,766	18.9	1,337	4.0	1,709	4.9	7,357	15.7	1,621	4.1	1,687	4.9	7,356	11.7	1,116	2.4	1,943	5.0
018	100.0	35,723	100.0	33,638	100.0	35,049	100.0	46,865	100.0	39,266	100.0	34,775	100.0	62,690	100.0	45,541	100.0	38,854	100.0
785		94,408		92,613		95,603		135,216		111,310		99,088		181,672		137,418		115,862	

		Subarea 8						Subarea 9						Subarea 10					
1960		1940		1950		1960		1940		1950		1960		1940		1950		1960	
	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
030	12.2	8,155	7.6	5,576	3.3	4,400	2.0	25,604	11.1	16,493	5.1	12,000	2.6	18,943	5.3	13,667	2.8	8,785	1.3
09	.3	23	--	19	--	20	--	38	--	51	--	100	--	493	.1	834	.2	1,010	.1
91	3.6	870	.8	1,551	.9	3,900	1.7	1,106	.5	3,363	1.0	8,400	1.8	9,506	2.7	11,103	2.2	26,619	3.8
33	14.9	14,426	13.4	38,474	23.0	54,079	23.7	28,751	12.4	55,784	17.2	93,900	20.0	65,480	18.5	109,984	22.1	146,904	20.6
29	13.4	9,138	8.5	14,138	8.5	17,718	7.8	12,530	5.4	19,999	6.2	29,120	6.2	44,959	12.7	77,590	15.6	94,607	13.3
34	10.7	831	.8	1,387	.8	1,985	.9	1,719	.7	3,038	.9	3,770	.8	3,947	1.1	4,365	.9	4,994	.7
0	--	150	.1	916	.6	1,201	.5	400	.2	802	.3	1,000	.2	3,700	1.1	6,689	1.3	7,938	1.1
31	.7	5,845	5.4	8,018	4.8	8,692	3.8	5,422	2.3	8,143	2.5	13,650	2.9	8,040	2.3	10,225	2.1	15,996	2.3
60	.7	454	.4	800	.5	1,023	.4	1,189	.5	2,398	.7	2,680	.6	1,467	.4	11,990	2.4	24,426	3.4
40	.1	268	.3	800	.5	1,480	.7	1,037	.5	1,500	.5	3,400	.7	1,096	.3	2,123	.4	3,835	.5
84	1.2	1,590	1.5	2,217	1.3	3,337	1.5	2,763	1.2	4,118	1.3	4,620	1.0	26,709	7.5	42,198	8.5	37,418	5.3
04	1.5	5,288	4.9	24,336	14.5	36,361	15.9	16,221	7.0	35,785	11.0	64,780	13.8	20,521	5.8	32,394	6.5	52,297	7.3
02	.9	1,936	1.8	18,984	11.3	32,601	14.3	5,056	2.2	19,391	6.0	43,300	9.2	13,018	3.7	23,144	4.6	40,359	5.7
53	.2	1,417	1.3	2,764	1.7	1,425	.6	6,434	2.8	9,929	3.0	12,380	2.6	2,263	.6	2,848	.6	3,537	.5
69	.4	1,935	1.8	2,588	1.5	2,335	1.0	4,731	2.0	6,465	2.0	9,100	2.0	5,240	1.5	6,402	1.3	8,401	1.1
63	31.0	23,474	21.8	45,620	27.2	62,399	27.4	55,499	24.0	75,691	23.3	114,400	24.4	94,422	26.6	135,588	27.3	183,318	25.8
17	64.0	66,693	61.9	117,318	70.0	156,001	68.4	145,596	62.9	239,432	73.8	336,225	71.8	224,311	63.2	340,502	68.5	492,723	69.2
36	5.0	17,580	16.3	4,636	2.8	9,600	4.2	30,442	13.1	9,274	2.9	18,000	3.8	35,925	10.2	21,002	4.2	35,583	5.0
36	100.0	107,747	100.0	167,574	100.0	228,000	100.0	231,537	100.0	324,397	100.0	468,625	100.0	354,658	100.0	497,092	100.0	711,624	100.0
6		255,905		392,643		573,215		527,145		743,501		1,083,601		823,006		1,200,326		1,756,291	

nds.

Table V-8

Population 1910-1960

Area	1910	1920	1930	1940	1950	1960
Nonmetropolitan						
1	68,548	68,791	70,979	67,789	58,431	59,649
2	77,904	68,945	57,096	59,998	54,739	54,785
3	92,599	99,832	89,979	94,408	92,613	95,603
4	136,312	148,403	138,742	135,216	111,310	99,088
5	157,387	180,807	177,220	181,672	137,418	115,862
6	175,909	180,745	197,754	174,344	132,165	107,711
7	84,456	92,147	87,955	102,194	97,608	100,496
Subtotal 1-7	793,115	839,670	819,725	815,621	684,284	633,194
Metropolitan						
8	143,032	190,086	230,870	255,905	392,643	573,215
9	269,656	351,215	458,629	527,145	743,501	1,083,601
10	244,741	375,281	635,470	847,547	1,227,055	1,787,886
Subtotal 8-10	657,429	916,582	1,324,969	1,630,597	2,363,199	3,444,702
Total 1-10	1,450,544	1,756,252	2,144,694	2,446,218	3,047,483	4,077,896

Table VIII-1

Mineral Quality of Trinity River Basin Waters
2020

Location	Total Dissolved Solids (mg/1.)		
	Average Annual	Maximum Monthly	Minimum Monthly
Reservoirs:			
Bridgeport	510	838	375
Boyd	491	529	471
Weatherford	683	796	501
Lake Worth-Eagle Mountain	609	895	171
Benbrook	806	825	779
Aubrey	558	637	504
Garza-Little Elm	542	613	492
Roanoke-Grapevine	590	717	533
Lavon	439	521	394
Forney	410	435	388
Terrell	496	672	398
Cedar Creek	139	176	124
Arlington	702	990	587
Navarro Mills	398	453	339
Waxahachie	311	337	287
Bardwell	597	760	501
Richland	431	481	408
Tehuacana	491	560	447
Lakeview & Mountain Creek	561	611	527
Tennessee Colony	645	732	590
Hurricane	479	561	449
Gail	662	927	569
Mustang	331	406	303
Caney	268	303	254
Upper Keechi	486	580	444
Lower Keechi	534	640	496
Bedias	484	567	445
Harmon Creek	755	775	737
Livingston	477	586	428
Long King	309	343	295
Wallisville	556	630	432
Points on Stream:			
Trinity River between river mile 534 and 389	726	841	500
Trinity River between river mile 339 and 174	623	711	523
Trinity River between river mile 129 and 35	547	640	479

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